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Unexpectedly large impact of forest management and grazing on global vegetation biomass

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Carbon stocks in vegetation have a key role in the climate system[1–4]. However, the magnitude, patterns and uncertainties of carbon stocks and the effect of land use on the stocks remain poorly quantified. Here we show, using state-of-the-art datasets, that vegetation currently stores around 450 petagrams of carbon. In the hypothetical absence of land use, potential vegetation would store around 916 petagrams of carbon, under current climate conditions. This difference highlights the massive effect of land use on biomass stocks. Deforestation and other land-cover changes are responsible for 53–58% of the difference between current and potential biomass stocks. Land management effects (the biomass stock changes induced by land use within the same land cover) contribute 42–47%, but have been underestimated in the literature. Therefore, avoiding deforestation is necessary but not sufficient for mitigation of climate change. Our results imply that trade-offs exist between conserving carbon stocks on managed land and raising the contribution of biomass to raw material and energy supply for the mitigation of climate change. Efforts to raise biomass stocks are currently verifiable only in temperate forests, where their potential is limited. By contrast, large uncertainties hinder verification in the tropical forest, where the largest potential is located, pointing to challenges for the upcoming stocktaking exercises under the Paris agreement.

The amount of carbon stored in terrestrial vegetation is a key component of the global carbon cycle[4]. Changes in carbon stored in vegetation biomass have a large effect on atmospheric CO_2 concentrations, due to either sequestering or release of carbon[2]. The urgency to conserve and, where appropriate, enhance the carbon reservoirs of terrestrial vegetation has long been recognized and is reflected by, for example, the inclusion of the land sector in the report of the United Nations Framework Convention on Climate Change (UNFCCC), the program for Reducing Emissions from Deforestation and Forest Degradation (REDD+), and the acknowledgement of biomass stocks as an essential climate variable[5]. Therefore, monitoring changes in biomass stocks is key for securing progress towards the commitment of halting global warming below 1.5 °C.

Although aboveground biomass stocks are straightforward to measure at the site level, their assessment at landscape-to-global scales is time consuming, costly and requires extrapolations[5]. Remote sensing is well-established for wall-to-wall mapping of biomass stocks, but the methodological differences between different remote-sensing products[6–8] and their scale mismatch with ground data[9–11] hamper their comparability. Consequently, and despite efforts to improve observational databases[3], biomass stocks and their spatial distribution remain uncertain at the global scale (Extended Data Fig. 1).

Many studies of global changes focus on changes in vegetation biomass without quantifying absolute amounts of biomass stocks[2,12]. Such approaches are indispensable for tracing the role of vegetation in the carbon cycle over time, but do not allow calculations of, for example, restoration potentials. Furthermore, large gaps in our knowledge remain concerning the impact of various land-use activities on biomass stocks[1,2,13].

Informed design, implementation, monitoring and verification of land-based climate-change mitigation strategies require comprehensive and systematic stocktaking of the carbon stored in vegetation[14]. Beyond accounts of carbon-stock changes, stocktaking also needs to consider the potential and actual biomass stocks of terrestrial vegetation; the full impact of land use on biomass stocks, that is, both land cover conversion and land management; and the uncertainty of biomass stock estimates. Here, we compile such information, complementary to current approaches that quantify actual biomass stocks[6–8,15,16] (Extended Data Fig. 2).

We present seven global maps of the actual biomass stocks (Extended Data Fig. 3), here defined as the terrestrial, living, aboveground and belowground vegetation biomass measured in grams of carbon, based on remote sensing[6–8] and inventory-derived information[15,16]. Ecological literature on biomass stocks of natural zonal vegetation (Supplementary Tables 1, 2), and remote-sensing-derived information on natural vegetation remnants in ecozones, was combined with state-of-the-art biome maps (Methods), accounting for areas without vegetation, to obtain six reconstructions of potential biomass stocks, defined as biomass stocks that would exist without human disturbance under current environmental conditions (Methods, Extended Data Fig. 4). Because actual and potential biomass stocks both refer to the same environmental conditions, their difference isolates the effect of land use on biomass stocks (Methods).

Variation within both sets of maps was interpreted as an indicator of uncertainty, assuming that the uncertainty is the result of differences between approaches rather than measurement errors within a single approach. From the variation between the seven actual biomass estimates, we calculated a detection-limit map for stock changes (Methods). Permuting potential and actual maps resulted in 42 pairs, which enabled us to quantify the effects of land use on biomass stocks[17,18]. Note that spatial variability in biomass stocks at the landscape level, for example, owing to age class structure, variation in soil fertility or soil-water availability, is accounted for differently in estimates of the potential and actual biomass stocks (Methods). This could introduce a bias of unknown sign and size when interpreting the fine-scale spatial patterns of the biomass-stock reduction maps.

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