

Can a forest keep absorbing carbon forever?

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A forest can keep photosynthesizing without continually increasing the amount of carbon it stores. Carbon enters through photosynthesis and leaves through respiration, decomposition, disturbance and movement out of the area being counted. Whether the forest is a net sink depends on the difference between those flows, not on the presence of green leaves alone.

“Forever” makes the question harder than “for a long time.” Evidence that an old forest still gains carbon does not establish unlimited future accumulation. Equally, a forest with little net annual gain can contain a large carbon stock whose loss would matter. Stock, uptake rate and the persistence of storage are three different properties.

1. Define the forest being counted

A carbon budget needs a boundary. Are we counting living trees, all vegetation, or vegetation plus dead wood, litter and soil within a defined area? Moving carbon from a living tree into dead wood reduces one pool while initially leaving the combined inventory largely unchanged. Calling that transfer an immediate atmospheric emission would count the wrong boundary.

Time matters too. A daytime measurement during active growth is not an annual budget. Nor does one quiet year represent an interval that includes a major disturbance. Comparing two reported sink estimates requires comparing their areas, pools and timescales before comparing their numbers.

IPCC's assessment of the land carbon cycle distinguishes gross emissions and removals and discusses why satellite, inventory and modelling estimates can cover different components. [1] A precise number cannot compensate for an unstated boundary.

2. A transparent numerical budget

Consider a hypothetical hectare over one year. Suppose photosynthesis fixes 20 tonnes of carbon, plant respiration returns 10 tonnes, and microbial and other heterotrophic respiration returns 8 tonnes. Assume for this example that there are no additional imports, exports or disturbances, and that all relevant pools are included.

The net gain is $20 - 10 - 8 = 2$ tonnes of carbon per hectare per year. Photosynthesis is ten times that net gain. Reporting the gross input as if it were the sink would therefore exaggerate the result by a factor of ten in this invented example.

Now hold photosynthesis at 20 but increase total respiration from 18 to 20. The net gain becomes zero even though photosynthesis continues. If a further 3 tonnes leave the defined inventory during the year through a disturbance or export, the stock falls by 3 tonnes under these assumptions.

The calculation is conservation, not a set of typical forest measurements. Its lesson is that a small residual can sit between much larger opposing flows. Estimating that residual requires attention to uncertainties in both sides, rather than measuring one side carefully and ignoring the other.

3. Old does not automatically mean carbon-neutral

Luyssaert and colleagues' 2008 synthesis found continuing carbon accumulation in many old forests and challenged the assumption that old-growth forests must be carbon-neutral. Their analysis drew on forest carbon-flux estimates compiled from the literature and databases. [2] The bounded conclusion relevant here is that age alone does not establish a zero sink.

The size of the inferred sink has been contested. Gundersen and colleagues re-examined the underlying estimates and argued that old-growth uptake had been overestimated, raising concerns about flux measurements, soil accumulation and differences in management history. [3] In their reply, Luyssaert and colleagues acknowledged questions requiring investigation but rejected the claim that the criticism established consistently poor flux measurements. [4] This exchange concerns quantitative inference, not a universal age at which photosynthesis stops.

A useful reading of the disagreement preserves both constraints. Continued uptake in an old stand is possible; assigning one universal annual rate to all old forests is not justified by that statement. The age of large trees is also not a complete record of an area's disturbance or management history.

4. A stock cannot grow linearly without limit in a finite box

If a bounded ecosystem stores carbon at a fixed positive net rate r , then after a time t its stock has increased by rt . Extending that rule indefinitely makes the stored mass increase without bound. A finite forest area with finite storage capacity cannot satisfy that extrapolation forever.

This logical limit does not identify the year in which a real forest's uptake will slow. Storage capacity, soil processes, changing vegetation and environmental conditions make that an empirical question. Nor does it forbid export from a forest into another reservoir; it requires that the exported carbon be counted in that other reservoir, with its own persistence and losses.

A simple stock-and-loss model sharpens the distinction. Let C be a carbon stock, I a constant input and kC a loss proportional to stock, with k positive. Then $dC/dt = I - kC$. The equilibrium stock is I/k . Input continues at equilibrium, but net accumulation is zero because loss balances input.

This is an illustration, not a calibrated forest model. Real inputs and loss rates change, pools have different turnover times and disturbances are not a smooth proportional drain. The model shows why continued throughput and unlimited net accumulation are different claims.

5. A forest is more than one growing tree

The death of a tree changes the distribution of carbon among pools. Subsequent decomposition can return carbon to the atmosphere over time, while surviving and regenerating plants continue taking it up. Across a landscape, stands in different stages can contribute different balances. IPCC discusses regrowth, disturbance and the limitations of representing these processes in land models. [1]

The future balance can also change with water availability, temperature, nutrients and atmospheric carbon dioxide. More of one growth resource does not eliminate the limits imposed by the others. It is therefore unsafe to project a measured uptake rate indefinitely under the assumption that the conditions supporting it will remain fixed.

The answer depends on the scale of the question. An individual stand, a shifting landscape mosaic and the entire global forest area are different systems. A local loss can coexist with a regional gain, or the reverse. Neither result should be silently transferred to the other scale.

6. Storage still matters when the sink slows

Suppose two hypothetical forests each contain a substantial carbon stock, but one is gaining carbon faster this year. That comparison ranks their current net changes; it does not rank the consequence of losing their existing stocks. A reservoir with a small inflow can still hold much material.

Similarly, a year of net uptake does not establish that the added carbon is stored permanently. Future disturbance, decomposition and land-use change affect its fate. These statements follow from keeping inventory and change separate, not from assigning a commercial value to either forest.

What we know reasonably well is the need to account for opposing flows and multiple pools. What remains uncertain in a particular forest includes its future disturbance history and the response of its components to changing conditions. The unresolved quantitative questions do not justify replacing the budget with “trees absorb carbon” or with “old forests do nothing.”

A forest can remain a net sink for a long time, including at old ages. It cannot be assumed to add carbon indefinitely at a fixed rate within a finite, unchanged area. And a slowing sink does not make the carbon already stored there disappear from the scientific question.

Related reading

Article 019, “How can we estimate a future climate without knowing each day's weather?”, discusses conditional projections. Here the future carbon balance is one of the quantities whose assumptions need to remain visible.

References

- [1] IPCC. Climate Change 2021: The Physical Science Basis. Chapter 5: Global Carbon and Other Biogeochemical Cycles and Feedbacks. <https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/>
- [2] S. Luyssaert et al. Old-growth forests as global carbon sinks. *Nature* 455, 213–215 (2008). <https://doi.org/10.1038/nature07276>
- [3] P. Gundersen, E. E. Thybring, T. Nord-Larsen, L. Vesterdal, K. J. Nadelhoffer and V. K. Johannsen. Old-growth forest carbon sinks overestimated. *Nature* 591, E21–E23 (2021). <https://doi.org/10.1038/s41586-021-03266-z>
- [4] S. Luyssaert, E.-D. Schulze, A. Knohl, B. E. Law, P. Ciais and J. Grace. Reply to: Old-growth forest carbon sinks overestimated. *Nature* 591, E24–E25 (2021). <https://doi.org/10.1038/s41586-021-03267-y>