Where's the Forest Carbon?

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This discussion explores the role of forest soils in sequestering carbon. It is important to note a complication in discussion of carbon and the carbon cycle in relation to global warming. While some discussions focus on carbon, others focus on carbon dioxide. Although, on a unit mass basis other greenhouse gases are more powerful global warming agents, because of its atmospheric concentration, carbon dioxide is the most important greenhouse gas in terms of its impact on warming. However, when discussions focus on carbon, it's important to appreciate that when a metric ton (tonne) of carbon in the soil or vegetation is volatilized as carbon dioxide, the atoms in that tonne of carbon each combine with two oxygen atoms. Carbon has a mass of 12 grams per mole, while oxygen clocks in at 16 grams per mole. Thus 12 tonnes of carbon combine with 32 tonnes of oxygen to produce 44 tonnes of carbon dioxide. The mass ratio between the carbon (12) and carbon dioxide (44) is thus 1:3.67meaning one tonne of carbon volatilized produces 3.67 tonnes of atmospheric carbon dioxide.

Where are the carbon stocks on Earth and what is the current flux?

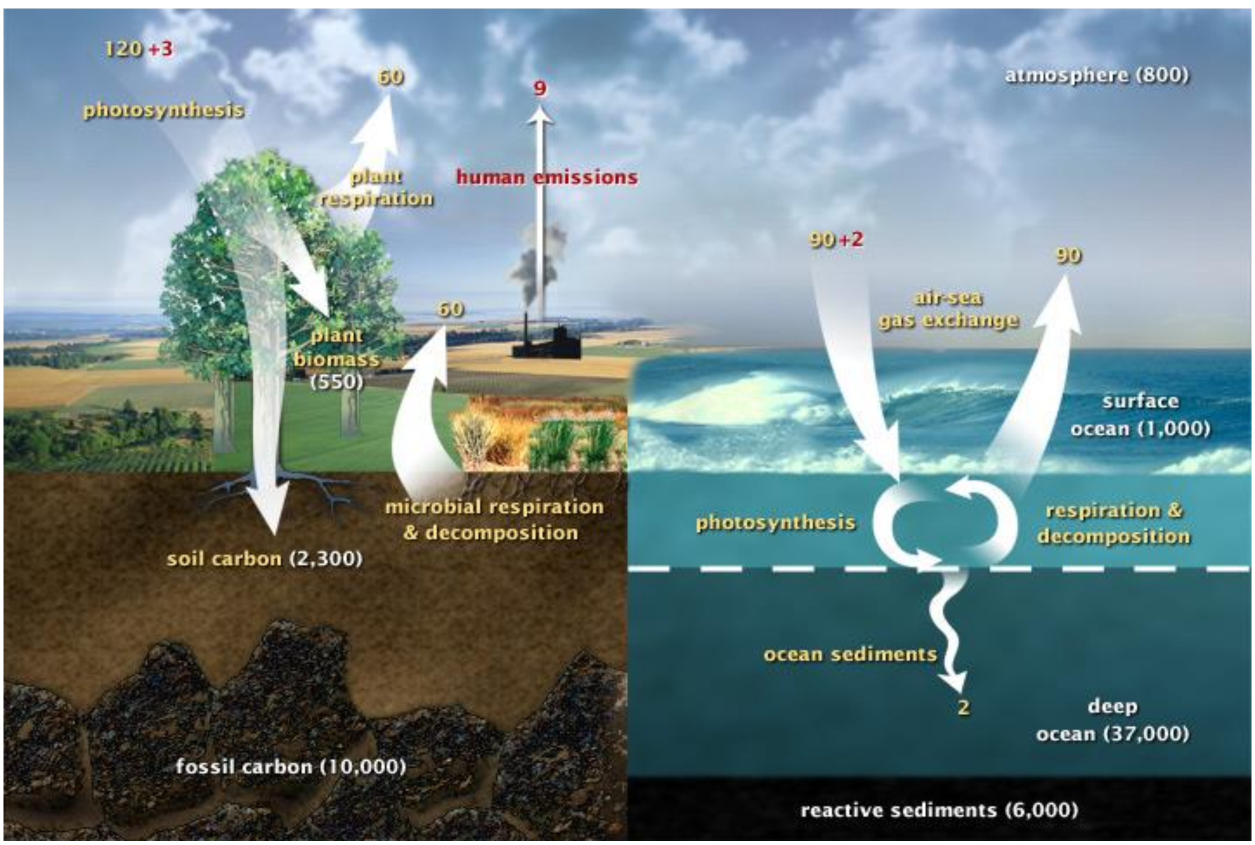

Figure 1. Where the carbon is located in gigatons C. White is stored, yellow is natural annual flux, red is annual human-induced flux. https://earthobservatory.nasa.gov/features/CarbonCycle

Figure 1 depicts the location of carbon stores on the planet. Note that the 800 GT of carbon (equivalent to 2,936 GT carbon dioxide in the atmosphere) is exceeded by a factor of approximately 3 by the carbon stocks in the soil 2,300 GT C (equivalent to 8441 GT CO_2) while rocks at 10,000 GT C (equivalent to 36,700 GT CO_2) surpass this total. Meanwhile, soils contain 550 GT C, (equivalent to 2,018.5 GT CO_2) and the natural cycle involving plant photosynthesis absorbs just about the same amount of C from the atmosphere as is emitted into the atmosphere by plant respiration combined with soil microbial respiration and decomposition. Our oceans also store some 38,000 GT of C (equivalent to 139,460 GT CO_2) and the exchange of C between ocean and atmosphere is almost in balance except for the 2 GT of human-induced C absorbed by oceans. Overall, the flux indicates that human emissions result in a net increase in atmospheric carbon of (9 - 3 - 2) GT of C, or some 25 GT CO_2. Regrettably, this excess of emissions over capture is actually increasing, and has now reached some 40 GT annually (https://www.wri.org/blog/2019/12/co2-emissions-climb-all-time-high-again-2019-6-takeaways-latest-climate-data). Unfortunately, carbon dioxide is not the only greenhouse gas we emit. When we include the other major greenhouse gases (methane, nitrous oxide, and the fluorinated gases) we find the annual emissions of all greenhouse gases measured in terms of their carbon dioxide equivalent, represents some 50 GT of carbon dioxide (https://ourworldindata.org/greenhouse-gas-emissions#:~:text=Greenhouse%20gases%20are%20measured%20in,were%20around%2035%20billion%20tonnes). This is equivalent to 13.62 (50/3.67) GT carbon.

Which biological systems store the most carbon? Many of us learned in High School that the major sink of carbon is the tropical rainforest. As more research has been conducted, we have

BIOME	AREA m km^2	Gt C Veg	Gt C Soil	GT C Per km^2 Vegetation + soil = total
Rainforest	**17.6**	**212**	**216**	**12.045 + 12.273 = 24.318**
Temperate Forest	**10. 4**	**59**	**100**	**5.673 + 9.615 = 15.288**
Taiga	**13.7**	**88**	**471**	**6.423 + 34.379 = 40.802**
Chaparral	**12.5**	**9**	**295**	**0.720 + 23.600 = 24.320**
Grassland	**22.5**	**66**	**264**	**2.933 + 11.733 = 14.667**
Cropland	**16.0**	**3**	**128**	**0.188 + 8.000 = 8.188**
Desert	**45.5**	**8**	**191**	**176 + 4.197 = 4.373**
Tundra	**9.5**	**6**	**121**	**0.632 + 12.737 = 13.368**

Table 1. Distribution of Carbon in global natural systems (aboveground and soils).
https://icp.giss.nasa.gov/education/modules/carbon/projects/investigate2.html

learned more about carbon storage. Table 1 depicts the pattern of carbon storage in terrestrial systems both globally and per square kilometer. Among the patterns evident in these data is the proportion of carbon stored in soil as opposed to vegetation. While rainforests store considerable carbon in vegetation and soil (about the same in each), notice that taiga forests (boreal coniferous forest), though storing less in the vegetation, store a huge amount of Carbon in the soil. Indeed, such a large mass of the Carbon is stored in soil that this ecosystem overall exceeds rainforest in its carbon storage capacity both globally and per square kilometer. However, note that this is entirely a function of the soil carbon. Meanwhile, although temperate forests exhibit lower C totals in vegetation and soil, they still store a higher proportion of C per unit area in the soil than the vegetation. In 2011, McKinley *et al*. reported on forest carbon density and forest soil carbon density in forest systems across the U.S. (Figure 2) and the carbon content of the soil and non-soil forest components (Figure 3). These graphs indicate that, throughout the United States, a high proportion of the carbon is stored in soils.

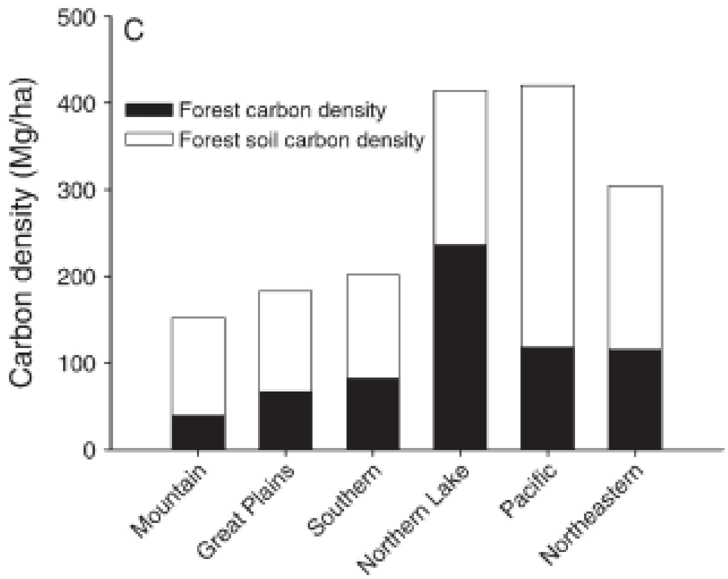

Figure 2. Forest carbon density and forest soil carbon density in forest systems across the U.S. McKinley et al 2011, https://www.fs.fed.us/rm/pubs_other/rmrs_2011_mckinley_d001.pdf

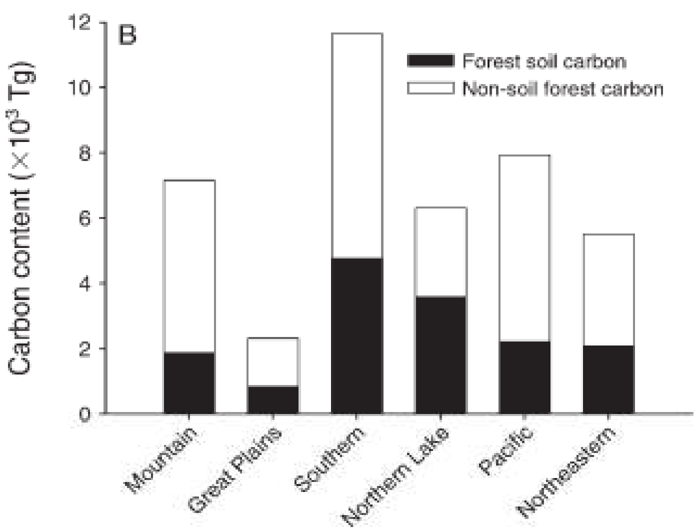

Figure 3. Carbon content of soil and non-soil forest components across the U.S. McKinley et al 2011, https://www.fs.fed.us/rm/pubs_other/rmrs_2011_mckinley_d001.pdf

Meanwhile, in a 2018 report of the Forest Carbon Accounting Project released by the Oregon Global Warming Commission (Figure 4), it is evident that the same pattern occurs in Oregon

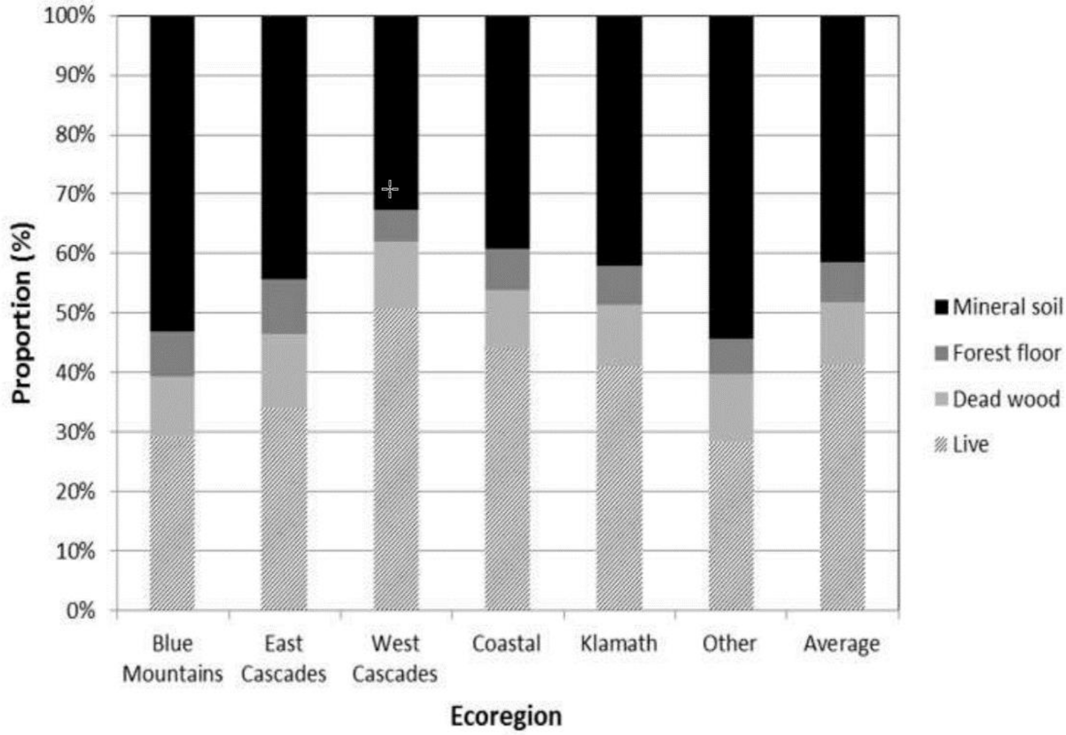

Figure 4. Distribution of carbon stores among major pools across Oregon Ecoregions. Oregon Global Warming Commission 2018
https://www.oregon.gov/ODF/ForestBenefits/Documents/Forest%20Carbon%20Study/OGWC-Forest-Carbon-Project-Report-2018.pdf

Region	Tons C / Acre	Above-ground live trees	Above-ground snags	Downed woody material	Forest Floor	Soils
Statewide Average	~ 90	35%	4%	7%	7%	47%
Blue Mountains	63.5	24%	4%	7%	7%	58%
East Cascades	63.3	28%	3%	9%	9%	51%
Klamath	108.2	36%	4%	5%	6%	49%
West Cascades	131.6	44%	5%	8%	5%	38%
Other Locations	75.7	25%	2%	5%	6%	62%
Coastal Range	131.2	385	3%	7%	7%	45%

Table 2. Distribution of carbon in Oregon forests. OGWC 2017 Forest Advisory Sub-Committee Report to Legislature 2017. Unpublished courtesy copy

with forests in the Blue Mountains storing over 50% of their carbon in the mineral component of the soil. Indeed, in that forest system, only 40% of the carbon is stored in the live vegetation. Soils in Oregon forests contribute substantially to the overall ecosystem storage of carbon in our forests.

Meanwhile, as depicted in Figure 5, forest soils across the U.S.are important storehouses of carbon.

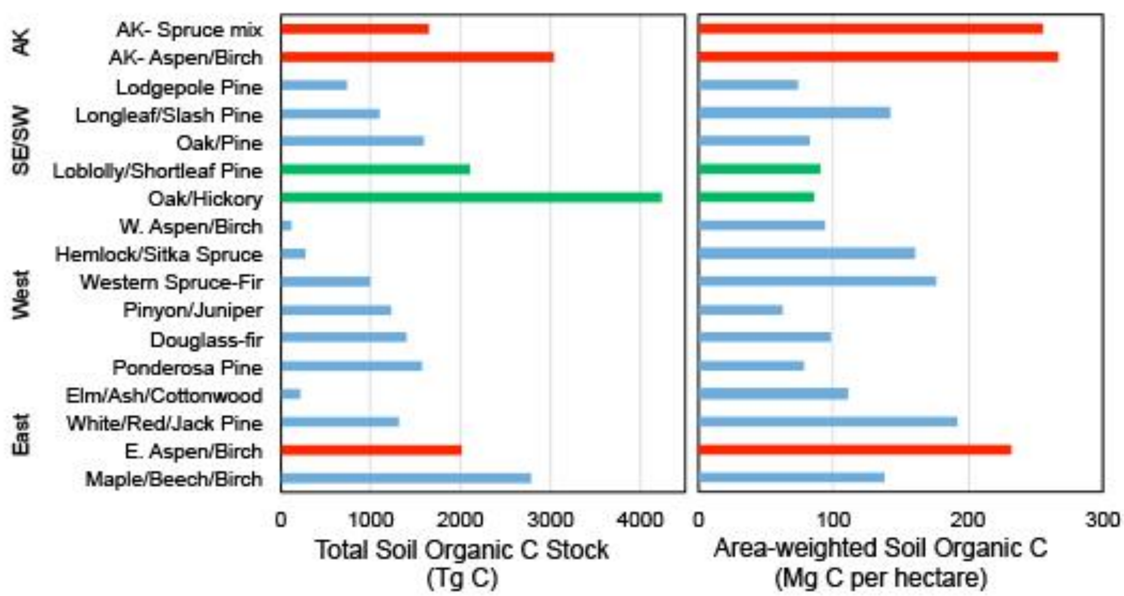

Figure 5. Stocks of soil organic carbon (SOC) across forest type in the U.S.
https://www.fs.usda.gov/ccrc/topics/forest-soil-carbon

"At the global level, 19 percent of the carbon in the earth's biosphere is stored in plants, and 81 percent in the soil. In all forests, tropical, temperate and boreal together, approximately 31 percent of the carbon is stored in the biomass and 69 percent in the soil. In tropical forests, approximately 50 percent of the carbon is stored in the biomass and 50 percent in the soil." (IPCC 2000 in http://www.fao.org/3/ac836e/AC836E03.htm).

Additional Thoughts:

That such a high proportion of the system carbon is stored in the soil probably helps to explain why wildfires in the state result in a relatively low contribution to the state's greenhouse gas emissions since very few fires impose sufficient damage broadly across the landscape that they combust soil carbon to any great depth.

Conditions which impede decomposition are often related to the accumulation of soil carbon, such as a lack of oxygen (high water table) and cold temperatures. D'Amore, D.; Kane, E. 2016.

Climate Change and Forest Soil Carbon. (August, 2016). U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. www.fs.usda.gov/ccrc/topics/forest-soil-carbon

Accompanying oxygen availability, and temperature, moisture, is a critical factor promoting decomposition. Dry, cool, and oxygen depleted conditions decrease decomposition and result in accumulation of soil organic matter and thus soil carbon. This explains the high C content in boreal ecosystems. Meanwhile, the warmer, moister conditions in many tropical systems presumably result in a more rapid flux of carbon through the soil, with lower accumulation.

Interestingly, Ontl et al (2012) indicate that 2/3rds of the increase in atmospheric carbon dioxide comes from burning fossil fuels while the remaining 1/3rd comes from land use change such as clearing forests and cultivation practices. (https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/)