Forest Carbon Resources

Bormann, B.T. & Kramer, M. G. (2008). Can ecosystem-process studies contribute to new management strategies in coastal Pacific Northwest and Alaska? *Northwest Science*, *72*(2), 77-83. https://eurekamag.com/research/003/059/003059021.php
(see #1 in Diagrams, below)

Chadid Hernandez, M. (2024). *Estimating carbon stocks and fluxes in an experimental logging trial within British Columbia's inland temperate rainforest*. UNBC thesis https://doi.org/10.24124/2024/59531

D'Amore David and Kane, Evan (2023) Forest soil carbon and climate change. USDA FS Climate Change Resource Centre https://www.climatehubs.usda.gov/sites/default/files/Forest-Soil-Carbon-Climate-Change_CCRC.pdf

Dean, C., Kirkpatrick, J. B., & Friedland, A. J. (2017). Conventional intensive logging promotes loss of organic carbon from the mineral soil. *Global Change Biology*, *23*(1), 1–11. https://doi.org/10.1111/gcb.13387

DellaSala, D. A., Keith, H., Sheehan, T., Strittholt, J., Mackey, B., Connolly, M., Werner, J. R., & Fredeen, A. L. (2022). Estimating carbon stocks and stock changes in Interior Wetbelt forests of British Columbia, Canada. *Ecosphere*, *13*(4), e4020. https://doi.org/10.1002/ecs2.4020

Dymond, C. C. (2012). Forest carbon in North America: Annual storage and emissions from British Columbia's harvest, 1965–2065. *Carbon balance and management*, *7*(1), 1-20.
https://cbmjournal.biomedcentral.com/articles/10.1186/1750-0680-7-8/figures/3
(see #2 in Diagrams, below)

Government of British Columbia. (2023). Provincial Inventory of Greenhouse Gas Emissions.
https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory#:~:text=in%202021%2C%20B.C.'s%20gross,emissions%20reduction%20and%20sectoral%20targets

Harmon, M. E., Ferrell, W. K., Franklin, J. F (1990). Effects on carbon storage of conversion of old-growth forests to young forests. *Science, 247*(4943), 699-702. https://pubmed.ncbi.nlm.nih.gov/17771887/

Harmon, M. E. (2019). Have product substitution carbon benefits been overestimated? A sensitivity analysis of key assumptions. *Environmental Research Letters*, *14*(6), 065008. https://iopscience.iop.org/article/10.1088/1748-9326/ab1e95

Howard, C. Dymond, C. C. Griess, V.C., Tolkien-Spurr, D. and van Kooten, G.C. (2021) Wood product carbon substitution benefits: a critical review of assumptions. *Carbon Balance and Management*, *16*(1), 1-11. https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-021-00171-w

James, J., & Harrison, R. (2016). The Effect of Harvest on Forest Soil Carbon: A Meta-Analysis. *Forests*, *7*(12), Article 12. https://doi.org/10.3390/f7120308

Krishnan, P., Black, T. A., Jassal, R. S., Chen, B., Nesic, Z. (2009). Interannual variability of the carbon balance of three different-aged Douglas-fir stands in the Pacific Northwest, *Journal Of Geophysical Research*, *114*(G4). https://ameriflux.lbl.gov/community/publication/interannual-variability-of-the-carbon-balance-of-three-different-aged-douglas-fir-stands-in-the-pacific-northwest/

Law, B. E., Moomaw, W. R., Hudiburg, T. W., Schlesinger, W. H., Sterman, J. D., & Woodwell, G. M. (2022). Creating strategic reserves to protect forest carbon and reduce biodiversity losses in the United States. *Land*, *11*(5), 721. https://www.mdpi.com/2073-445X/11/5/721

Malcolm, J. R., Holtsmark, B., & Piascik, P. W. (2020). Forest harvesting and the carbon debt in boreal east-central Canada. *Climatic Change*, *161*(3), 433-449. https://academic.daniels.utoronto.ca/forestry/wp-content/uploads/sites/4/2020/04/Malcolm_online_2020_Article_ForestHarvestingAndTheCarbonDe.pdf

> *"After a first rotation of harvesting, carbon stocks declined 33–50% relative to stocks in the natural, fire-dominated landscapes and payback periods ranged from 92 to 757 years."*

Matsuzaki, E., Sanborn, P., Fredeen, A. L., Shaw, C. H., & Hawkins, C. (2013). Carbon stocks in managed and unmanaged old-growth western redcedar and western hemlock stands of Canada's inland temperate rainforests. *Forest Ecology and Management*, *297*, 108–119. https://doi.org/10.1016/j.foreco.2012.11.042

Mayer, M., Prescott, C. E., Abaker, W. E. A., Augusto, L., Cécillon, L., Ferreira, G. W. D., James, J., Jandl, R., Katzensteiner, K., Laclau, J.-P., Laganière, J., Nouvellon, Y., Paré, D., Stanturf, J. A., Vanguelova, E. I., & Vesterdal, L. (2020). Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. *Forest Ecology and Management*, *466*, 118127. https://doi.org/10.1016/j.foreco.2020.118127

Mildrexler, D. J., Berner, L. T., Law, B. E., Birdsey, R. A., & Moomaw, W. R. (2020). Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest. *Frontiers in Forests and Global Change*, *3*. https://doi.org/10.3389/ffgc.2020.594274

Mildrexler, D. J., Berner, L. T., Law, B. E., Birdsey, R. A., & Moomaw, W. R. (2023). Protect large trees for climate mitigation, biodiversity, and forest resilience. *Conservation Science and Practice*, *5*(7), e12944. https://doi.org/10.1111/csp2.12944

Moomaw, W. R., Masino, S. A., & Faison, E. K. (2019). Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good. *Frontiers in Forests and Global Change*, *2*. https://doi.org/10.3389/ffgc.2019.00027

Moomaw, W. R., & Law, B. E. (2023). A call to reduce the carbon costs of forest harvest. https://www-nature-com.proxy.lib.sfu.ca/articles/d41586-023-02238-9

Nave, L. E., Vance, E. D., Swanston, C. W., & Curtis, P. S. (2010). Harvest impacts on soil carbon storage in temperate forests. *Forest Ecology and Management*, *259*(5), 857–866. https://doi.org/10.1016/j.foreco.2009.12.009

Noormets, A., Epron, D., Domec, J. C., McNulty, S. G., Fox, T., Sun, G., & King, J. S. (2015). Effects of forest management on productivity and carbon sequestration: A review and hypothesis. *Forest Ecology and Management*, *355*, 124–140. https://doi.org/10.1016/j.foreco.2015.05.019

Peng, L., Searchinger, T. D., Zionts, J., & Waite, R. (2023). The carbon costs of global wood harvests. *Nature*, *620*(7972), 110-115. https://pmc.ncbi.nlm.nih.gov/articles/PMC10396961/
(see #3 in Diagrams, below)

Polanyi, M., Skene, J. and Simard, A. (2024). *2024 Logging Emissions Update: Reported greenhouse gas (GHG) emissions from logging in Canada double after revision to government data.* Nature Canada, Natural Resources Defense Council, Nature Quebec. https://naturecanada.ca/wp-content/uploads/2024/09/2024-Logging-Emissions-Update-Report.pdf
(see #4 in Diagrams, below)

Power, K., & Gillis, M. D. (2006). *Canada's forest inventory 2001* (Vol. 408). Pacific Forestry Centre.

Pukkala, T. (2018). Carbon forestry is surprising. *Ecosystems*, *5*(11). https://forestecosyst.springeropen.com/articles/10.1186/s40663-018-0131-5

Roach, W. J., Simard S. W., Defrenne, C. E., Pickles, B. J., Lavkulich, L.M. & Ryan, T. L. (2021). Tree diversity, site index and carbon storage decrease with aridity in Douglas-fir forests in western Canada. *Frontiers in Forests and Global Change*, 4, 682076. https://www.frontiersin.org/articles/10.3389/ffgc.2021.682076/full#:~:text=Our%20results%20indicate%20that%20as,productive%2C%20carbon%2Drich%20forests
(see #5 in Diagrams, below)

> *Note: The forest carbon pool percentages were derived from three plots in the Malcolm Knapp (MK) forest, a mature second growth Douglas-fir forest in the Coastal Douglas-fir biogeoclimatic zone. It was the closest data available for a coastal temperate forest carbon pool measurement done in accord with the carbon pool methodology used in the carbon budget model (CBM), with which Canada measures forest carbon sequestration.*

Senez-Gagnon, F., Thiffault, E., Paré, D., Achim, A., & Bergeron, Y. (2018). Dynamics of detrital carbon pools following harvesting of a humid eastern Canadian balsam fir boreal forest. *Forest Ecology and Management*, *430*, 33–42. https://doi.org/10.1016/j.foreco.2018.07.044

Smith, J. E., Heath, L. S.; Skog, K. E. & Birdsey, R. A. (2006). Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 pp. https://research.fs.usda.gov/treesearch/22954
(see #6 in Diagrams, below)

Stephenson, N. L., Das, A. J., Condit, R., Russo, S. E., Baker, P. J., Beckman, N. G., ... & Zavala, M. A. (2014). Rate of tree carbon accumulation increases continuously with tree size. *Nature*, *507*(7490), 90-93. https://www.nature.com/articles/nature12914

Suchanek, T., Mooney, H. A., Franklin, J., Gucinski, H. & Ustin, S. (2004). Carbon dynamics of an old-growth forest. *Ecosystems.* 7. 421-426. 10.1007/s10021-004-0134-7. https://www.researchgate.net/profile/Tom-Suchanek/publication/273319184_Carbon_Dynamics_of_an_Old-growth_Forest/links/54fe0a720cf2eaf210b22bfc/Carbon-Dynamics-of-an-Old-growth-Forest.pdf

> *Note: The carbon flux tower in the Wind River Experimental Forest in Washington state, a 500 year old Douglas Fir/Hemlock stand, provides the only consistent old growth carbon flux data for the Pacific northwest. The three Canadian coastal carbon flux towers described in Krishnan et al. are on managed Douglas-fir forests on Vancouver Island and are all less than 100 years old (see Krishnan et al. source included here).*

https://ameriflux.lbl.gov/sites/site-search/#igbp=ENF
AmeriFlux is a network of PI-managed sites measuring ecosystem CO2, water, and energy fluxes in North, Central and South America. It was established to connect research on field sites representing major climate and ecological biomes, including tundra, grasslands, savanna, crops, and conifer, deciduous, and tropical forests.

Trofymow, J. A., Porter, G. L., Blackwell, B. A., Arksey, R., Marshall, V., & Pollard, D. (1997). Chronosequences for research into the effects of converting coastal British Columbia old-growth forests to managed forests: an establishment report. *Pacific Forestry Centre.*
https://osdp-psdo.canada.ca/dp/en/search/metadata/NRCAN-CFS-1-4898

Trofymow, J. A. & Bruce A. Blackwell. (1998). Changes in ecosystem mass and carbon distributions in coastal forest chronosequences. *Northwest Science*, *72*(2), 40-42. https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/5091.pdf
(see #7 in Diagrams, below)

Trofymow, J. A., Stinson, G. Kurz, W. A. (2008). Derivation of a spatially explicit 86-year retrospective carbon budget for a landscape undergoing conversion from old-growth to

managed forests on Vancouver Island, BC. *Forest Ecology and Management*, 256 (2008) 1677–1691
https://www.sciencedirect.com/science/article/abs/pii/S0378112708002235

Note: Data collected at the 2500 ha Oyster River area of Fluxnet-Canada's coastal BC Station second and third growth.

"Despite their high productivity, the area's forests are not likely to attain C densities of the landscape prior to industrial logging because the stands will not reach pre-logging ages."

Misinformation

Forestry for the Future: www.forestryforthefuture.ca

Forest Products Association: https://www.fpac.ca/

Diagrams

1. Source: Bormann, B. T. & Kramer, M. G. (2008). Can ecosystem-process studies contribute to new management strategies in coastal Pacific Northwest and Alaska? *Northwest Science*, *72*(2), 77-83.

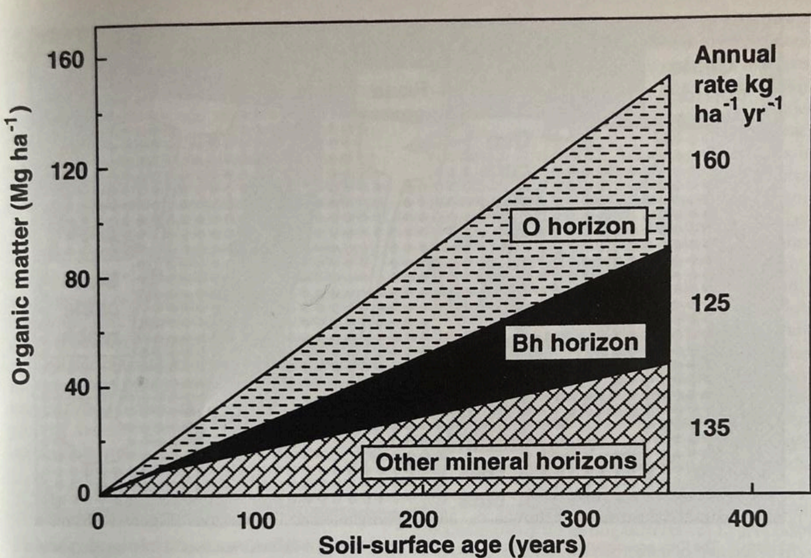


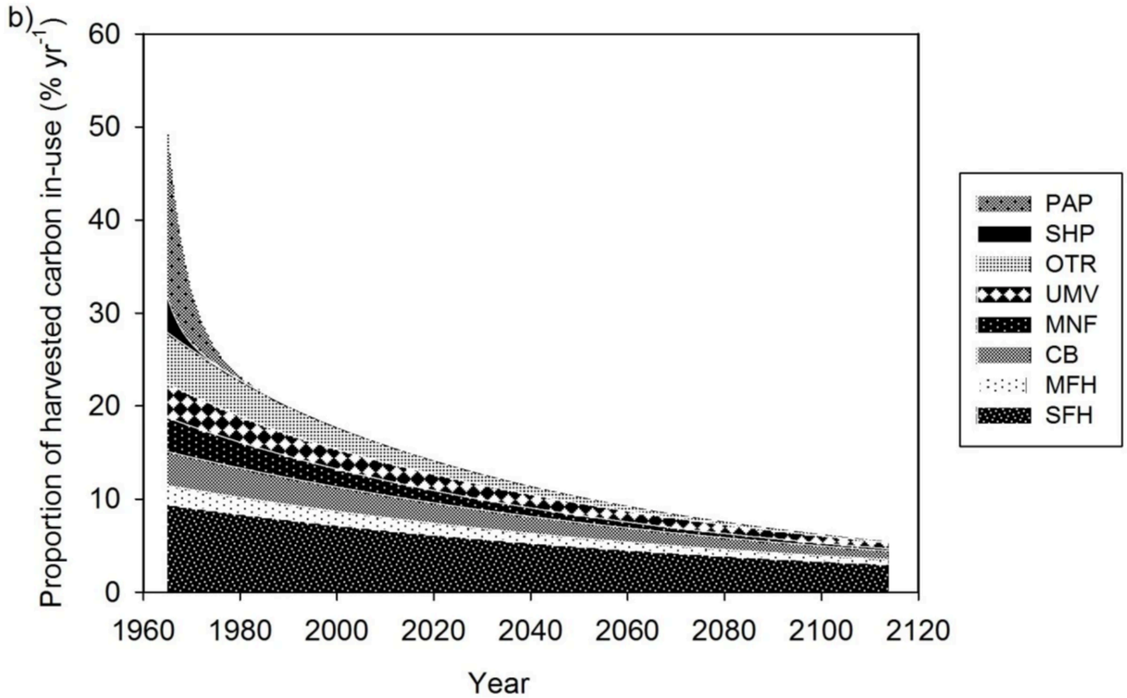
Figure 2. Rate of organic matter accumulation in podzols in southeast Alaska. Nutrients become immobilized, especially in the Bh horizon, and are freed only by soil disturbance, which is frequently provided by windthrow.

deeper rooting and early successional plants. If roots become confined to organic horizons, soils are hypothesized to become increasingly organic and infertile because trees can no longer mix mineral and organic horizons when windthrown. Harvesting trees before they can be windthrown and minimizing soil mixing during yarding almost eliminate soil mixing, which historically was a common natural disturbance. Concerns arising from the exclusion of soil disturbance from these sites include: loss of soil fertility—which is perhaps irreversible without drastic measures; loss of area in productive forest; and reduced viability of associated species (such as bears and badgers that den in rootwads). Maintaining the soil-mixing process appears to reverse nutrient immobilization, maintain or increase rooting depth, and increase weathering to supply base-element nutrients. A recent study has noted a marked 6-

Management Strategies Based on Knowledge of Windthrow and Podzolization

On Kuiu island, a management strategy is being proposed to better maintain natural disturbance processes in the harvest units (Crane and Rowan Mountain timber sales, draft EIS 1997, on file, Petersburg Ranger District, Petersburg, Alaska). A diameter-limit (41 to 97 cm dbh) and small gap harvest (Figure 3) is proposed to create a frequency distribution of gap sizes that more closely approximates natural disturbance patterns (Figure 4). Perhaps more important, some standing trees will uproot and not be salvaged; thus the possibilities of some root throw and downed logs are maintained. Because this strategy is new, an intensive monitoring program will assess, for example, the effect of wind exposure and sheltering on root

2. Source: Dymond, C. C. (2012). Forest carbon in North America: Annual storage and emissions from British Columbia's harvest, 1965–2065. *Carbon balance and management*, *7*(1), 1-20.
The carbon costs of global wood harvests.

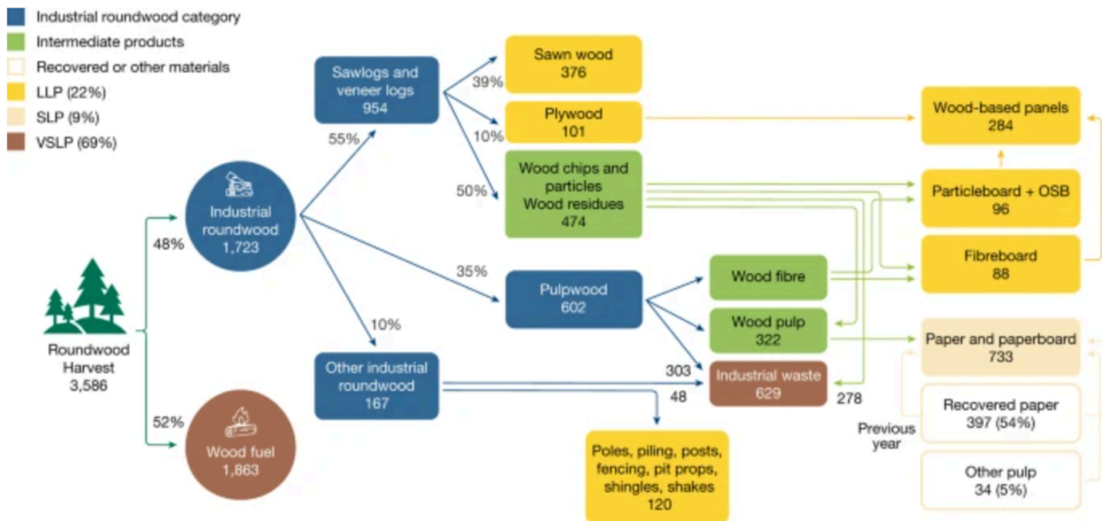


Estimates of C stored in in-use pools over one of the 150 year simulations: single family homes (SFH), multi-family homes (MFH), commercial buildings (CB), furniture and manufactured products (MNF), residential upkeep and moveable homes (UMV), shipping (SHP), other wood products (OTR), and paper (PAP). a) Annual C stocks in all in-use pools. Note that harvest and therefore input to these pools occurred from 1965 to 2065 only to demonstrate the different rates of loss after 2065. **b**) The decline of C stored in-use that originated from the 1965 harvest only.

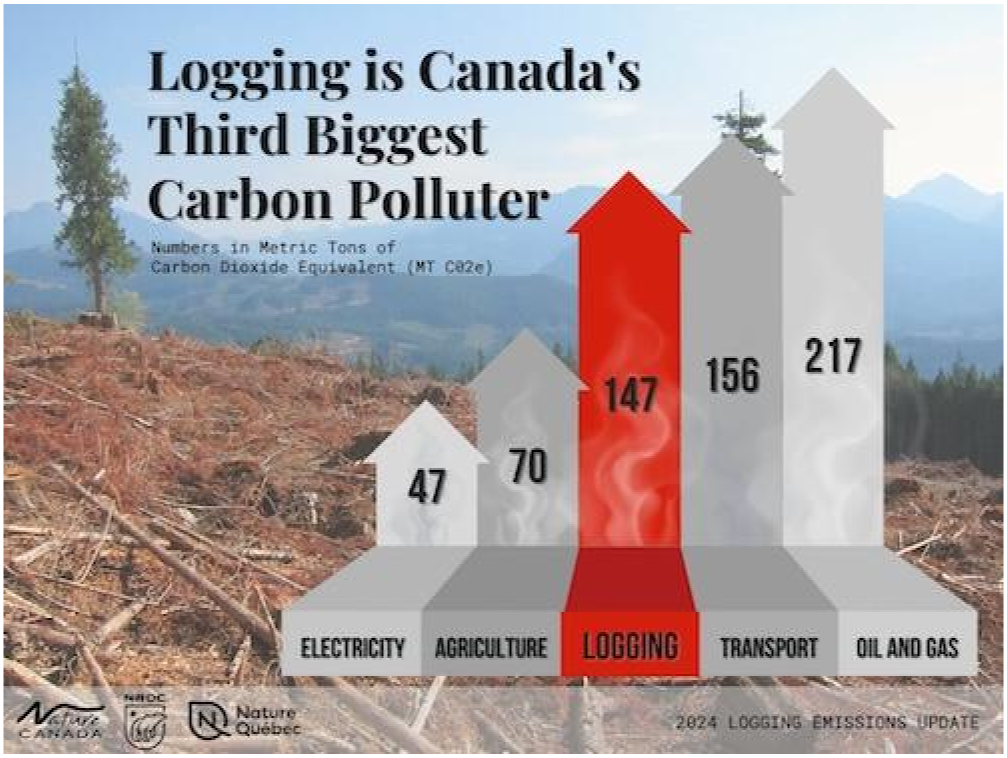
3. Source: Peng, L., Searchinger, T. D., Zionts, J., & Waite, R. (2023). The carbon costs of global wood harvests. *Nature*, *620*(7972), 110-115.

Because some wood products use 'wastes' of other wood products, we trace these consumed products back to required wood harvest levels. Figure 2 shows our estimate of annual global flows of wood from harvest to ultimate use for 2010.

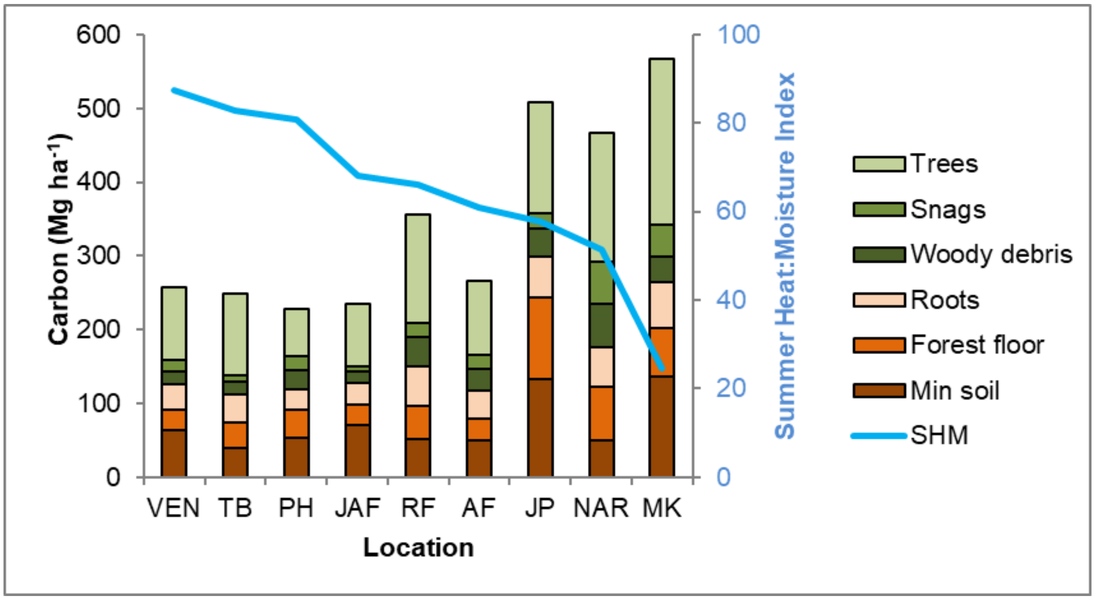
Fig. 2: Flowchart of 2010 global roundwood (million m^3), tracing the relationship between consumption of different wood products and wood harvests.



4. Source: Polanyi, M., Skene, J. and Simard, A. (2024). 2024 Logging Emissions Update: Reported greenhouse gas (GHG) emissions from logging in Canada double after revision to government data. Nature Canada, Natural Resources Defense Council, Nature Quebec. https://naturecanada.ca/wp-content/uploads/2024/09/2024-Logging-Emissions-Update-Report.pdf



5. Source: Roach, W. J., Simard S. W., Defrenne, C. E., Pickles, B. J., Lavkulich, L.M. & Ryan, T. L. (2021). Tree diversity, site index and carbon storage decrease with aridity in Douglas-fir forests in western Canada. *Frontiers in Forests and Global Change*, 4, 682076.
https://www.frontiersin.org/articles/10.3389/ffgc.2021.682076/full#:~:text=Our%20results%20indicate%20that%20as,productive%2C%20carbon%2Drich%20forests



Caption: "Distribution of carbon amongst the major pools, for the nine study locations. The locations are arranged in order of decreasing summer heat: moisture index (SHM), shown by the blue line. VEN, Venables; TB, Two-bit Creek, PH, Peterhope Lake; JAF, Jaffray; RF, Redfish Creek; AF, Alex Fraser; JP, John Prince; NAR, Narrows Creek, MK, Malcolm Knapp."

Notes:

1. The figure above is for unlogged mature (not old-growth) Douglas-fir forests. They are all interior sites except Malcolm Knapp. The most arid site (VEN) is near Cache Creek/ Spences Bridge. NAR is in the Interior Wet Belt. JP is up north near Ft St James. Malcolm Knapp on the coast is what the percentages of carbon in the different carbon pools were derived from.

2.Aridity (SHM) decreases along the x-axis from left to right (MK is the most humid, VEN is the most arid). Aridity values are based on 2001-2010 averages from ClimateBC.

3. This graph illustrates Summer Heat: Moisture Index.

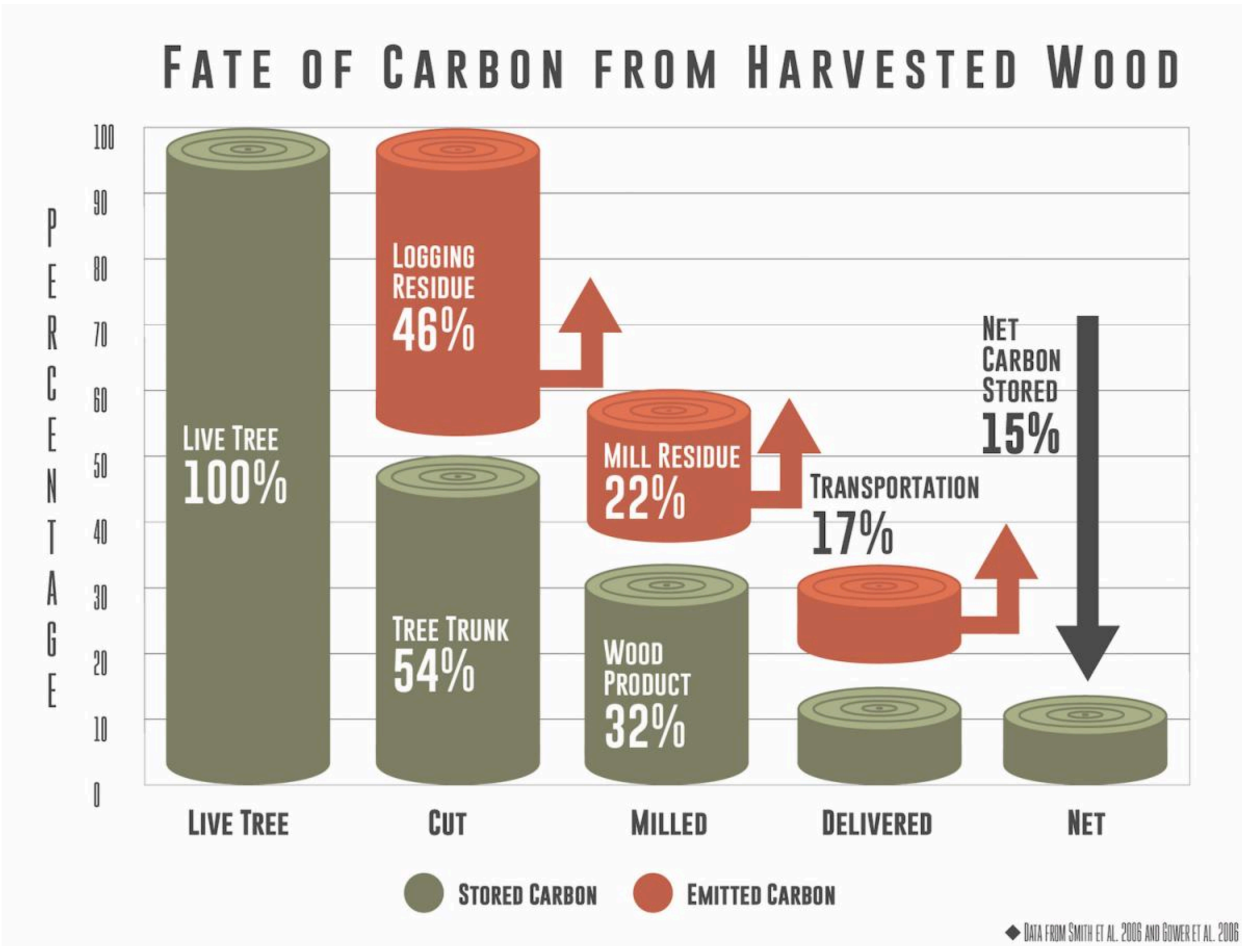
4. Understory plants were an insignificant carbon pool so aren't included.

4. "Trees " is aboveground stem, branches and bark.

6. "Roots" are tree roots, based on a default conversion factor from aboveground tree biomass.

7. Mineral soil carbon is only to a depth of 55 cm. Note that considerable carbon is also stored in mineral soil below 55 cm.

6. Source: Smith, J. E., Heath, L. S.; Skog, K. E. & Birdsey, R. A. (2006). Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 pp.



7. Source: Trofymow, J. A. & Bruce A. Blackwell. (1998). Changes in ecosystem mass and carbon distributions in coastal forest chronosequences. *Northwest Science*, 72(2), 40-42. https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/5091.pdf

Note: The old growth total carbon max for over 1000 tonnes per hectare comes from this diagram below, from the forest on the far right of the old growth plots. "Living" includes living trees and roots. Detrital is dead living matter.

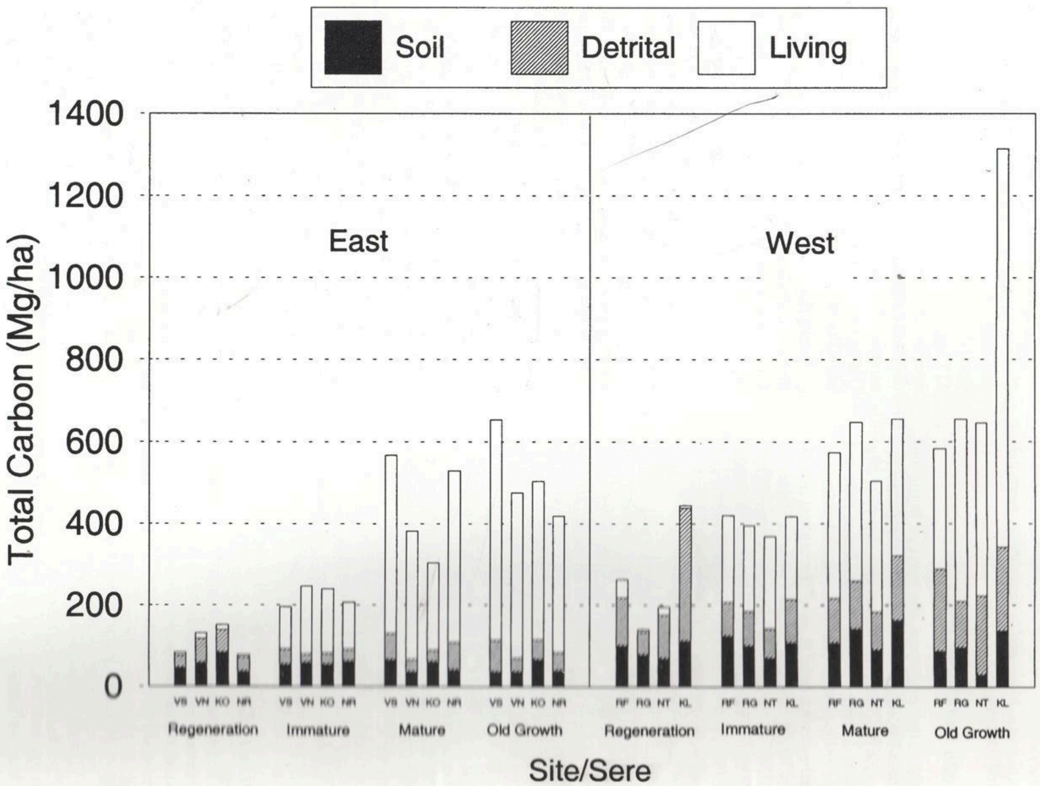


Figure 1. Living, detrital, and soil carbon for each plot, grouped by site and seral stage within the CWHxm (east) and CWHvm (west) biogeoclimatic subzones.