Climate Forests Campaign Coordinating Group: **Center for Biological Diversity ● Earthjustice ● Environment America ● Natural Resources Defense Council ● Sierra Club ● Oregon Wild ● Standing Trees ● The Larch Company ● Wild Heritage ● WildEarth Guardians**

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Re: Request for Information (RFI) on Federal Mature and Old-Growth Forests

We appreciate the Forest Service (USFS) and Bureau of Land Management (BLM) moving promptly on key directions in Executive Order 14072. There is an urgent need to make forward progress on the Order's directive to conserve mature and old-growth forest and retain carbon and biodiversity.[1] Nationwide, the country has lost most of its mature and old-growth forests due primarily to historic and ongoing logging. Federal forests, however, still contain important expanses of these forests.[2] But they continue to be threatened by logging, compromising the ability of the nation's forests to act as natural climate solutions and imperiling their myriad co-benefits.[3] Fortunately, unlike some ecological threats to these key resources, logging on federal lands is under the unilateral control of management agencies and reversing these alarming trends is well within their authority and responsibility.

The change needed in both USFS and BLM's management to end this loss from logging is straightforward: protect mature and older stands—and mature and older trees outside of such stands—from logging, with exceptions such as those articulated below. To ensure that the change is durable, it needs to be memorialized in a regulation binding under future administrations. The extensive public and environmental review process for such a regulation needs to start now, rather than awaiting completion of your broader inquiry into definitions and inventories for a variety of other purposes in the executive order. Input from this RFI about mature and old-growth forests and trees can be folded into the rulemaking process and incorporated in environmental review documents.

Initiating the rulemaking now would support the aims of President Biden's Executive Order 14072. The Order establishes an immediately effective, ongoing policy to "conserve America's mature and

[1] Exec. Order No. 14,072, 87 Fed. Reg. 24,851 (April 22, 2022). https://www.federalregister.gov/documents/2022/04/27/2022-09138/strengthening-the-nations-forests-communities-and-local-economies.
[2] According to one study in peer review, approximately 50 million acres of federal mature and old-growth forests are not in protected areas. DellaSala, D. A. et al. in review. "Mature and Old-Growth Forest Contributions to Large-Scale Conservation Targets in the Conterminous USA." (Submitted to the agency portal under separate cover.)
[3] Climate Forests Coalition. "Worth More Standing: 10 Climate-Saving Forests Threatened By Federal Logging." (2022). https://www.climate-forests.org/_files/ugd/73639b_03bdeb627485485392ac3aaf6569f609.pdf.

old-growth Forests on federal lands" and to "manage forests on Federal lands, which include many mature and old-growth forests" for purposes including "retain[ing] and enhanc[ing] carbon storage" and "conserv[ing] biodiversity."[4] The goal of the directive to define, inventory, and develop strategies for mature and old-growth forests is expressly "[t]o **further** conserve mature and old-growth forests."[5] While the inventory and associated activities can progress on a more extended timeline, initiating a rulemaking in the near-term addressing the logging threat is fully consistent with the Order's urgent prioritization of carbon storage and biodiversity conservation.

For the specific purpose of protecting from logging the irreplaceable carbon, biodiversity, watershed, and ecosystem values of older forests and trees on federal lands with a simple, generally applicable, and easily administrable rule, maturity can be effectively defined as beginning no later than 80 years. And for the purposes of such regulatory protection, no definition of "old growth" is necessary as the executive order requires the protection of both. Once a definition of what constitutes a mature forest or tree is determined, then any forest stand or tree older than that is protected under the rule.

Eighty years is a straightforward metric for maturity that can be readily operationalized in the field across all types of federal forest by, for instance, using the robust data in USFS's Forest Inventory and Analysis (FIA) database to determine a typical diameter at breast height associated with 80 years for a given species in a given forest type. We urge adoption of a simple definition to ensure ready and consistent implementation in the field, which will in turn yield reliable protective results. You are well positioned already to initiate a rulemaking limiting logging to no later than the age of 80 for stands and for individual trees in mixed age stands. And doing so now will help ensure there is time for a robust public process and exemplary environmental review.

Importantly, setting a protective threshold at 80 years for logging will not impede appropriate wildfire mitigation work. Older, larger trees are not the primary contributors to fire risk—they have often developed characteristics that make them more resistant to wildfires, such as thicker bark and higher branches.[6] Using this threshold would still permit the cutting and removal of smaller and younger trees, which act as the surface and ladder fuels that are significant contributors to uncharacteristic forest fires.[7] Beyond this, the regulation should also allow some entry into mature stands in damaged forests—generally those heavily managed and fire-suppressed stands that naturally experienced fire every 35 years or fewer. The agencies should be able to kill trees older than 80 years of age in such stands where the best available science shows that is necessary to achieve important non-commercial goals. But those trees should be removable only where uncontroverted science indicates that it is necessary to secure public safety or other over-riding public imperatives.

As explained in more detail below, 80 years is an effective definition for maturity for the purposes of protecting mature and old-growth forests and trees from logging for three overarching reasons.

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[4] Exec. Order No. 14,072, 87 Fed. Reg. 24,851 (April 22, 2022). https://www.federalregister.gov/documents/2022/04/27/2022-09138/strengthening-the-nations-forests-communities-and-local-economies.

[5] *Id.* (emphasis added)

[6] Agee, J. K. "Fire ecology of Pacific Northwest Forests." Island Press (1993). https://islandpress.org/books/fire-ecology-pacific-northwest-forests; Hood, S., et al. "Fire resistance and regeneration characteristics of Northern Rockies tree species." In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (2018). https://www.fs.fed.us/database/feis/pdfs/other/FireResistRegen.html.

[7] Agee, J.K. and C. N. Skinner. "Basic principles of forest fuel reduction treatments." Forest Ecology and Management (2005) Vol. 211, Iss. 1-2: 83-96. https://doi.org/10.1016/j.foreco.2005.01.034.

First, setting a threshold at 80 years secures significant protection for carbon stores and sequestration capacity associated with older forests. Second, 80 is within the established indicators of maturation for forest types that are present in the US's federal forests, such as the peak of overall growth rate or the onset of sexual maturity. Third, a threshold of 80 would deliver significant co-benefits, including for ecological function, biodiversity protection, and hydrological functions.

I. Protecting Stands and Trees Starting at 80 Years Would Preserve Our Federal Forests' Role as Climate Champions.

Chief among the reasons for selecting 80 years as a protective threshold for mature and old-growth forests and trees is climate protection. Implementing natural climate solutions across all forest ownerships in the U.S. could mitigate up to 423.7 million tonnes of CO_2 equivalent per year by 2030.[8] Mature and old-growth forests and trees on federal lands are carbon storage and carbon sequestration champions. Using 80 years as the threshold for regulatory protection safeguards these carbon benefits now to help meet critical carbon reduction goals. Protecting these forests thus presents an important opportunity to realize key parts of natural climate solutions in the United States. Moreover, protecting trees from logging at 80 years will enable the relatively quick recovery of old-growth forests that have been lost to logging. If the United States is to assert global leadership in fighting the climate crisis, it must protect the essential carbon-rich values present in older forests and trees.

a. Carbon Storage in the Live Wood Pool

Protecting federal forests from logging starting at 80 years of age would capture most of the above-ground stored carbon on those forests, nationwide. The percentage in a given forest varies depending on that forest's structure, geography, history, and climate. In the Gifford Pinchot National Forest, analysis of information available in USFS's FIA database indicates that stands at and above 80 years represent approximately 80 percent of that forest's total aboveground carbon in live trees. In the national forests of the southern Appalachians, stands at and above 80 years comprise approximately 70 percent of those forests' aboveground carbon in live trees. In New England's national forests and Wisconsin's Chequamegon-Nicolet National Forest, such stands contain approximately 50 percent of the forests' aboveground carbon in live trees (see Appendix 1 for analysis).

As a tree ages and grows larger, research indicates that it will continue to absorb carbon at an increasing rate, storing carbon faster than younger trees do.[9] As it develops, a tree's total leaf area increases, which means more light can be intercepted, which, through photosynthesis, means more atmospheric carbon absorbed.[10] Moreover, the increase in the rate of carbon accumulation continues

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[8] Griscom, B. W. et al. "Natural Climate Solutions." Proceedings of the National Academy of Sciences (2017) Vol. 114, Iss. 44: 11645–11650. https://doi.org/10.1073/pnas.1710465114.

[9] Stephenson, N. L. et al. "Rate of tree carbon accumulation increases continuously with tree size." Nature (2014) Vol. 507: 90-93. https://doi.org/10.1038/nature12914.

[10] *Id.*; Xu, C-Y. et al. "Age-related decline of stand biomass accumulation is primarily due to mortality and not to reduction in NPP associated with individual tree physiology, tree growth or stand structure in a Quercus-dominated forest." Journal of Ecology (2012) Vol. 100, Iss. 2: 428-440. https://doi.org/10.1111/j.1365-2745.2011.01933.x; Pregitzer, K. S. and E. S. Euskirchen. "Carbon cycling and storage in world forests: biome patterns related to forest age." Global Change Biology (2004) Vol. 10, Iss. 12: 2052-2077. https://doi.org/10.1111/j.1365-2486.2004.00866.x; Mildrexler, D. J. et al. "Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest." Frontiers in Forests and Global Change (2020). https://doi.org/10.3389/ffgc.2020.594274.

even as a tree's overall growth rate per unit leaf area declines.[11] Older, larger trees thus hold significantly more carbon than their younger brethren in the forest.[12] And the older stands that these trees dominate hold a substantial and disproportionate portion of a forest's carbon.

Furthermore, 80 years is an effective threshold for protecting the bulk of carbon storage in U.S. federal forests. In many federal forests, stands grow increasingly rare the further away from 80 one gets. This is particularly true in the country's eastern and midwestern forests, where the history of logging has left few older stands.[13] In the Green and White Mountains National Forests, FIA data indicate that stands older than 90 represent approximately 25 percent of aboveground carbon in live trees and stands older than 100 represent just 10 percent of aboveground carbon in live trees. In the southern Appalachian national forests, those figures are approximately 45 percent and 25 percent, respectively (see Appendix 1 for analysis).

b. <u>Carbon Sequestration</u>

By 80 years of age, most temperate forest types represented on U.S. federal forestlands have already attained peak rates of annual carbon sequestration at the stand level.[14] Though the precise causes are still being studied,[15] this peak tends to correlate with canopy closure, and intra-stand population dynamics—e.g., trees within a stand dying and replacing their sequestration ability with carbon storage—play a role.[16] As seen in the net primary productivity data discussed below and presented in Appendix 1, the timing of the peak varies based on forest type and site condition (soil quality, aspect, elevation, water availability, local climate, etc.).[17] In the temperate forests of the United

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[11] Stephenson, N. L. et al. "Rate of tree carbon accumulation increases continuously with tree size." Nature (2014) Vol. 507: 90-93. https://doi.org/10.1038/nature12914.

[12] Mildrexler, D. J. et al. "Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest." Frontiers in Forests and Global Change (2020). https://doi.org/10.3389/ffgc.2020.594274; Lutz, J. A. et al. "Global importance of large-diameter trees." Global Ecology and Biogeography (2018) Vol. 27, Iss. 7: 849-864. https://doi.org/10.1111/geb.12747; Brown, S. A.. "Spatial distribution of biomass in forests of the eastern USA." Forest Ecology and Management (1999) Vol. 123, Iss. 1: 81-90. https://doi.org/10.1016/S0378-1127(99)00017-1.

[13] Johnson, C. and D. Govatski. "Forests for the People." Island Press (2013). https://islandpress.org/books/forests-people.

[14] He, L. et al. "Relationships between net primary productivity and forest stand age in U.S. forests," Global Biogeochemical Cycles (2012) Vol. 26, Iss. 3. https://doi.org/10.1029/2010GB003942; Birdsey, R. A. et al. "Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of U.S. national forests." General Technical Report RMRS-GTR-402. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (2019). https://doi.org/10.2737/RMRS-GTR-402; Dugan, A. J. et al. "Forest Sector Carbon Analyses Support Land Management Planning and Projects: Assessing the Influence of Anthropogenic and Natural Factors." Climatic Change (2017) Vol. 144: 207-220. https://doi.org/10.1007/s10584-017-2038-5.

[15] Kutsch W.L. et al. "Ecophysiological characteristics of mature trees and stands - Consequences for old-growth forest productivity." In: Wirth C., Gleixner G., Heimann M. (editors) Old-growth forests. Springer (2009) pp. 57-79. https://doi.org/10.1007/978-3-540-92706-8_4.

[16] Stephenson, N. L. et al. "Rate of tree carbon accumulation increases continuously with tree size." Nature (2014) Vol. 507: 90-93. https://doi.org/10.1038/nature12914; Lorenz K. and R. Lal. "Effects of disturbance, succession and management on carbon sequestration." In: Lorenz K., Lal R. (editors) Carbon sequestration in forest ecosystems. Springer (2010) pp. 103-57. https://doi.org/10.1007/978-90-481-3266-9_3.

[17] He, L. et al. "Relationships between net primary productivity and forest stand age in U.S. forests," Global Biogeochemical Cycles (2012) Vol. 26, Iss. 3. https://doi.org/10.1029/2010GB003942.

States, maximum annual carbon sequestration tends to happen relatively early in a stand's development, generally before—and often significantly before—80 years.[18]

Critically, once this peak rate has been achieved, the rates do not rapidly collapse. Instead, stands settle into significantly high annual rates of sequestration while they continue to accumulate carbon stocks. In some stands, the rate of sequestration will trend toward an equilibrium state where carbon dioxide sequestered via photosynthesis equals carbon dioxide emitted through respiration.[19] In others, the rate of sequestration will remain relatively constant, with only gradual deceleration.[20] And still others, such as pinyon-juniper, appear to avoid a decline in sequestration and, instead, continually, if gradually, increase carbon accumulation rates over the course of centuries.[21] All told, as a general matter, the rate of carbon accumulation remains robust well into a stand's post-peak development.[22]

c. **Carbon Storage in the Dead Wood Pool**

The carbon accumulated by trees throughout their lives will persist as wood through the end of the tree's life and beyond. Once an older tree dies from old age or natural disturbance the carbon contained in its wood does not disappear into the atmosphere. Instead, the tree—and the lion's share of the carbon it holds—is retained in the forest as a snag (a standing dead tree) or as coarse woody debris (CWD; a fallen dead tree) slowly decomposing over decades to centuries. This remains true even in scenarios where older, larger trees are affected by wildfire.[23] For example, research on post-fire decomposition rates in the nearly half-million acre Biscuit fire in southwest Oregon reported that 85 percent of the carbon remained 10 years after the fire.[24] Additionally, field

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[18] Birdsey, R. A. et al. "Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of U.S. national forests." General Technical Report RMRS-GTR-402. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (2019). https://doi.org/10.2737/RMRS-GTR-402.
[19] Hudiburg, T. W. et al. "Carbon dynamics of Oregon and Northern California forests and potential land-based carbon storage." Ecological Applications (2009) Vol. 19, Iss. 1: 163-180. https://doi.org/10.1890/07-2006.1; Pregitzer, K. S. and E. S. Euskirchen. "Carbon cycling and storage in world forests: biome patterns related to forest age." Global Change Biology (2004) Vol. 10, Iss. 12: 2052-2077. https://doi.org/10.1111/j.1365-2486.2004.00866.x.
[20] Gough, C. M., et al. "Disturbance, complexity, and succession of net ecosystem production in North America's temperate deciduous forests." Ecosphere (2016) Vol. 7, Iss. 7. https://doi.org/10.1002/ecs2.1375.
[21] Birdsey, R. A. et al. "Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of U.S. national forests." General Technical Report RMRS-GTR-402. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (2019). https://doi.org/10.2737/RMRS-GTR-402.
[22] He, L. et al. "Relationships between net primary productivity and forest stand age in U.S. forests," Global Biogeochemical Cycles (2012) Vol. 26, Iss. 3. https://doi.org/10.1029/2010GB003942; Law, B. E. et al. "Changes in carbon storage and fluxes in a chronosequence of ponderosa pine." Global Change Biology (2003) Vol. 9, Iss. 4: 510-524. https://doi.org/10.1046/j.1365-2486.2003.00624.x; Keeton, W. S. et al. "Late-Successional Biomass Development in Northern Hardwood-Conifer Forests of the Northeastern United States." Forest Science (2011) Vol. 57, Iss. 6: 489-505. https://doi.org/10.1093/forestscience/57.6.489.
[23] Campbell, J. L. et al. "Pyrogenic carbon emission from a large wildfire in Oregon, United States." Journal of Geophysical Research (2007) Vol. 112. https://doi.org/10.1029/2007JG000451; Meigs, G. W. "Forest Fire Impacts on Carbon Uptake, Storage, and Emission: The Role of Burn Severity in the Eastern Cascades, Oregon." Ecosystems (2009) Vol. 12: 1246-1267. https://doi.org/10.1007/s10021-009-9285-x; Stenzel, J. E. et al. "Fixing a snag in carbon emissions estimates from wildfires." Global Change Biology (2019) Vol. 25, Iss. 11: 3985-3994. https://doi.org/10.1111/gcb.14716; Harmon, M.E., et al. 2022. "Combustion of aboveground wood from live trees in megafires, CA, USA." Forests (2022) Vol. 13 Iss. 3. https://doi.org/10.3390/f13030391.
[24] Campbell, J. L. et al. "Carbon emissions from decomposition of fire-killed trees following a large wildfire in Oregon, United States," Journal of Geophysical Research: Biogeosciences (2016) Vol. 121, Iss. 3: 718–730. https://doi.org/10.1002/2015JG003165.

measurements in two of California's largest, most severe forest fires, the Rim and Creek fires in the Sierra Nevada, indicated that approximately 99% of the carbon remained in the large trees postfire.[25]

After they die, larger, mature trees often decay more slowly than smaller, younger trees, in both snag and CWD form. Snags are an important aboveground carbon pool[26] and can take upwards of a century (or more) to decompose.[27] Their longevity is due in large part to being more isolated from the agents of decomposition that live on the forest floor (fungi, bacteria, etc.).[28] One of the primary determinants of fall rates among snags is mean annual temperature: warmer climates tend to accelerate decomposition and tree collapse.[29] That said, older, larger trees tend to last substantially longer as snags than smaller trees.[30] In the Cascade Mountains of Oregon, for example, snags of trees greater than 21 inches diameter at breast height lasted 2 to 5 times longer than smaller trees of the same species.[31]

CWD often decomposes faster than snags, but the CWD generated by older stands can still retain carbon for extended periods of time.[32] In the Pacific Northwest, for instance, large, water-saturated logs in old-growth Douglas-fir forests can last for more than 300 years.[33] In eastern U.S. forests, CWD can last for well over a century, depending on the species.[34] And even as this dead wood decomposes, not all its carbon is lost to the atmosphere—some is absorbed into the forest soil.[35]

Conversely, logging releases much of the stored forest carbon to the atmosphere in a relatively short time through the transportation and manufacturing process (and particularly if the biomass is

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[25] Harmon, M.E., et al. 2022. "Combustion of aboveground wood from live trees in megafires, CA, USA." Forests (2022) Vol. 13 Iss. 3. https://doi.org/10.3390/f13030391.
[26] Lutz, J.A. et al. "The importance of large-diameter trees to the creation of snag and deadwood biomass." Ecological Processes (2021) Vol. 10. https://doi.org/10.1186/s13717-021-00299-0.
[27] Kelsey, R.G. et al. "Changes in Heartwood Chemistry of Dead Yellow-Cedar Trees that Remain Standing for 80 Years or More in Southeast Alaska." Journal of Chemical Ecology (2005) Vol. 31: 2653–2670. https://doi.org/10.1007/s10886-005-7618-6.
[28] Maser, C. et al. "From the forest to the sea: a story of fallen trees." General Technical Report PNW-GTR-229. USDA Forest Serv. Pacific NW Res. Sta. (1988) pp. 153. https://doi.org/10.2737/PNW-GTR-229; Harmon, M.E., Hua, C. "Coarse woody debris dynamics in two old-growth ecosystems. Comparing a deciduous forest in China and a conifer forest in Oregon." Bioscience (1991) Vol. 41, Iss. 9: 604-610. https://doi.org/10.2307/1311697; Bradford, M.A., et al. "Belowground community turnover accelerates the decomposition of standing dead wood." Ecology (2021) Vol. 102, Iss. 11. https://doi.org/10.1002/ecy.3484.
[29] Bradford, M.A., et al. "Belowground community turnover accelerates the decomposition of standing dead wood." Ecology (2021) Vol. 102, Iss. 11. https://doi.org/10.1002/ecy.3484.
[30] Dunn, C.J. and J.D. Bailey. "Temporal dynamics and decay of coarse wood in early seral habitats of dry-mixed conifer forests in Oregon's Eastern Cascades." Forest Ecology and Management (2012) Vol. 276: 71-81. https://doi.org/10.1016/j.foreco.2012.03.013.
[31] Mellen-McLean, K. and J. L. Ohmann. "Snag Dynamics in Western Oregon and Washington." United States Department of Agriculture, Forest Service (2016) https://apps.fs.usda.gov/r6_decaid/views/snag_dynamics.html.
[32] Harmon, M.E. et al. "Ecology of Coarse Woody Debris in Temperate Ecosystems." Advances in Ecological Research (1986) Vol. 34: 59-234. https://doi.org/10.1016/S0065-2504(03)34002-4.
[33] Means, J.E. et al. "Comparison of decomposition models using wood density of Douglas-fir logs." Canadian Journal of Forest Research (1985) Vol. 15, Iss. 6: 1092-1098. https://doi.org/10.1139/x85-178.
[34] Russell, M.B., et. al. "Residence times and decay rates of downed woody debris biomass/carbon in eastern US Forests." Ecosystems (2014) Vol. 17: 765-777. https://doi.org/10.1007/s10021-014-9757-5; Tyrell, L.E. and T.R. Crow. "Dynamics of dead wood in old-growth hemlock-hardwood forests of northern Wisconsin and northern Michigan." Canadian Journal of Forest Research (1994) Vol. 24. Iss. 8: 1672-1683. https://doi.org/10.1139/x94-216; MacMillan, P.C., "Decomposition of coarse woody debris in an old-growth Indiana forest." Canadian Journal of Forest Research (1988) Vol. 18, Iss. 11: 1353-1362. https://doi.org/10.1139/x88-212.
[35] Magnússon, R. Í. et al. "Tamm Review: Sequestration of carbon from coarse woody debris in forest soils." Forest Ecology and Management (2016) Vol. 377: 1-15. https://doi.org/10.1016/j.foreco.2016.06.033.

burned for energy).[36] Substantial quantities of logging debris will decompose or be burned. The milling of logs into products can quickly release stored carbon from the harvested tree boles. And products like pulp, paper, and biofuel have a very short retention time before being emitted as CO_2.

II. <u>80 Years Fits Within Criteria for Assessing Biological Maturation.</u>

Using 80 years of age as a threshold for maturity in a policy that protects forests from logging is within current scientific assessments of biological maturity for U.S. forests. Research points toward multiple methods for assessing the maturation process in forest ecosystems. Below we discuss several means of assessing maturity and demonstrate how an 80-year threshold for defining maturity for the purposes of preventing logging fits within these assessments. Precisely delineating the determinants of forest development has occupied the science of forestry for upwards of a century and will likely continue to do so.[37] But the agencies need not resolve this on-going ecological discussion to settle on an effective definition of maturity for purposes of protecting mature and old-growth forests and trees from logging.

a. <u>Net Primary Productivity</u>

One approach for assessing stand maturity is by looking at the peak of net primary productivity (NPP). This marks a key turning point in a stand's development: the age at which a stand's carbon accumulation rate reaches a maximum.[38] Before this point, the rate of carbon accumulation in a stand is increasing. After it, the rate of carbon accumulation levels off or begins to decline at the stand level. As noted above, the causes of age-related decline in stand growth remain subject to debate, but one of the key physiological changes associated with the NPP peak is canopy closure.[39]

Almost all forest types in the National Forest System reach this peak before 80 years of age, indicating that an 80-year logging rule is consistent with protecting mature forests. Generally, the peak of NPP tends to be achieved relatively early in the development of temperate forest stands. Pregitzer and Euskirchen's 2004 global analysis found that "NPP peaked in the 11-30 years age class in temperate forests."[40] Statistical analyses on publicly available NPP data corroborate this trend

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[36] Law, B. E., et al. "Land use strategies to mitigate climate change in carbon dense temperate forests." Proceedings of the National Academy of Sciences of the United States of America (2018) Vol. 115, Iss. 14: 3663-3668. https://doi.org/10.1073/pnas.1720064115; Hudiburg, T. W. et al. "Meeting GHG reduction targets requires accounting for all forest sector emissions." Environmental Research Letters (2019) Vol. 14, Iss. 9. https://doi.org/10.1088/1748-9326/ab28bb; Sterman, J. et al, "Does wood bioenergy help or harm the climate?" Bulletin of the Atomic Scientists (2022) Vol. 78, Iss. 3: 128-138. https://doi.org/10.1080/00963402.2022.2062933.

[37] Assmann, E. "The Principles of Forest Yield Study" Pergamon (1970) pp 1-2. https://doi.org/10.1016/C2013-0-01587-3; Ryan, M.G. et al. "Age-Related Decline in Forest Productivity: Pattern and Process," Advances in Ecological Research (1997) Vol. 27: 213-262. https://doi.org/10.1016/S0065-2504(08)60009-4.

[38] Gower, S. T. et al. "Aboveground net primary production decline with stand age: potential causes," Trends in Ecology & Evolution (1996), 11, 9, pp. 378-382. https://doi.org/10.1016/0169-5347(96)10042-2; Ryan, M.G. et al. "Age-Related Decline in Forest Productivity: Pattern and Process," Advances in Ecological Research (1997) Vol. 27: 213-262. https://doi.org/10.1016/S0065-2504(08)60009-4; He, Liming et al. "Relationships between net primary productivity and forest stand age in U.S. forests." Global Biogeochemical Cycles (2012) 26: pp. 1-16. https://doi.org/10.1029/2010GB003942.

[39] Ryan, M.G. et al. "Age-Related Decline in Forest Productivity: Pattern and Process," Advances in Ecological Research (1997) Vol. 27: 213-262. https://doi.org/10.1016/S0065-2504(08)60009-4; He, L. et al. "Relationships between net primary productivity and forest stand age in U.S. forests," Global Biogeochemical Cycles (2012) Vol. 26, Iss. 3. https://doi.org/10.1029/2010GB003942.

[40] Pregitzer, K. S. and E. S. Euskirchen. "Carbon cycling and storage in world forests: biome patterns related to forest age." Global Change Biology (2004) Vol. 10, Iss. 12: 2052-2077. https://doi.org/10.1111/j.1365-2486.2004.00866.x.

among forest types within the National Forest System.[41] The average of peak NPP age values across all national forests is 54 ± 15 years while the peak NPP age value average weighted by area of national forest is 57 ± 15 years. The median is 50 years (see Appendix 2 for additional analysis and statistical method elaboration).

b. Culmination of Mean Annual Increment

Another metric that has been used to represent "biological maturity," culmination of mean annual increment,[42] shows that a logging threshold of 80 years is a reasonable approach to protecting mature stands and trees. Mean annual increment (MAI) is the average annual growth of a stand, generally defined by timber volume.[43] The culmination of MAI—CMAI—is the age at which the annual average volume growth is at a maximum.[44] This metric has a long vintage in silviculture and continues to be employed by USFS to evaluate stand development.[45] Literature assessing different forest types and geographies around the country show CMAI ages are frequently well below 80 (see Appendix 3 for additional analysis).

c. Individual Tree Maturity

Eighty years also captures the mature stage of development under assessments of maturity that are based on the physiological development of individual trees. At this level, "fully reproductive plants are considered to be mature."[46] The key signifier of this development is the tree's ability to consistently form and propagate seeds and cones in its natural state.[47] Additional biological changes are also attendant on the phase change from juvenility to maturity,[48] including, for example, changes

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[41] Birdsey, R. A. et al. "Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of U.S. national forests." General Technical Report RMRS-GTR-402. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (2019). https://doi.org/10.2737/RMRS-GTR-402.
[42] Johnson, D. L., J. F. Franklin, and K. N. Johnson. "Ecological Forest Management," Waveland Press (2018); Thomas, J.W. et al. "Forest Ecosystem Management: An Ecological, Economic, and Social Assessment." Forest Ecosystem Management Assessment Team (1993). p. IX-31. https://www.blm.gov/or/plans/nwfpnepa/FEMAT-1993/1993_%20FEMAT_Report.pdf.
[43] Burns, R. M. and B. H. Honkala (technical coordinators). "Silvics of North America, Volume 2: Hardwoods". Agriculture Handbook 654. USDA Forest Service (1990).
https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_2/silvics_v2.pdf.
[44] *Id.*
[45] Assmann, E. "The Principles of Forest Yield Study" Pergamon (1970). https://doi.org/10.1016/C2013-0-01587-3; Curtis, R. O. "Some Simulation Estimates of Mean Annual Increment of Douglas-Fir: Results, Limitations, and Implications for Management." Research Paper PNW-RP-471. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station (1994) p 471. https://doi.org/10.2737/PNW-RP-471; Franklin, J. F.; Spies, T. A. "Composition, function, and structure of old-growth Douglas-fir forests." In: Ruggiero, L. F.; Aubry, K. B.; Carey, A. B.; Huff, M. H. (tech. eds.) Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW-285. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station (1991) pp. 71-80; "Nantahala-Pisgah National Forests Land Management Plan." U.S. Department of Agriculture, Forest Service, Southern Region (January 2022) p. 314. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd987300.pdf.
[46] Bond, B. J. "Age-Related Changes in Photosynthesis of Woody Plants." Trends in Plant Science (2000) Vol. 5 Iss. 8: 349–53. https://doi.org/10.1016/S1360-1385(00)01691-5.
[47] Bond, B. J. "Age-Related Changes in Photosynthesis of Woody Plants." Trends in Plant Science (2000) Vol. 5 Iss. 8: 349–53. https://doi.org/10.1016/S1360-1385(00)01691-5; Greenwood, M.S. and K.W. Hutchison. "Maturation as a Developmental Process." In: Ahuja, MR. and W.J. Libby (editors) Clonal Forestry I. Springer (1993) pp. 14-33 https://doi.org/10.1007/978-3-642-84175-0_3; Hackett, W.P., "Juvenility, Maturation, and Rejuvenation in Woody Plants." In: Janick, J. (editor) Horticultural Reviews vol. 7. (1985) pp. 109-146.
https://doi.org/10.1002/9781118060735.ch3.
[48] Hackett, W. and J. Murray. "Maturation and rejuvenation in woody species." In: Ahuja, M.R. (editor) Micropropagation of Woody Plants. Springer (1993) pp 93-105. https://doi.org/10.1007/978-94-015-8116-5_6.

in leaf shape/morphology,[49] a peak of height growth rate,[50] decreased rooting ability,[51] and development of defense mechanisms.[52] The maturation of individual trees generally occurs quite early, between 1-50 years old.[53]

d. Relationship to the Development of a Framework Definition

Defining mature as beginning no later than 80 years in a regulation for the purpose of protecting trees and stands from logging is consistent with the agencies' process of developing a framework definition and inventory for mature and old-growth forests. That latter process is aimed at informing a range of agency activities that are different from ensuring that logging no longer avoidably decreases forest carbon. The rulemaking would affect decisions about logging.[54]

As such, a rulemaking to protect mature and old-growth trees and stands on federal lands from logging can and should begin immediately, even as the development of a broader framework definition is ongoing. As shown above, the evidence already available shows that stands on federal forests 80 years and older store an extraordinary amount of carbon. It would be counterproductive to imperil these carbon storage powerhouses by delaying a rulemaking until the completion of a lengthier definition and inventory process.

III. Mature Forests and Trees Provide Critical Ecological Co-Benefits.

Setting the threshold at 80 years would help retain significant ecological co-benefits, including high levels of biodiversity as directed by the Executive Order, due to the specific structural attributes and ecological processes that accompany mature forests.[55] Scientists have long recognized that mature forests across the country possess unique ecological features. One leading forest ecology textbook, for instance, argues that the "mature forest stage" is when "the initial cohort of trees lose their youthful appearance," "[o]verstory trees will achieve most of their height growth and crown spread," "[E]picormic or other adventitious branch systems may begin developing," and "[d]ecadent canopy and bole features . . . become more abundant."[56]

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49 Greenwood, M.S. and K.W. Hutchison. "Maturation as a Developmental Process." In: Ahuja, MR. and W.J. Libby (editors) Clonal Forestry I. Springer (1993) pp. 14-33 https://doi.org/10.1007/978-3-642-84175-0_3.
50 Bond, B. J. "Age-Related Changes in Photosynthesis of Woody Plants." Trends in Plant Science (2000) Vol. 5 Iss. 8: 349–53. https://doi.org/10.1016/S1360-1385(00)01691-5; Bond B. J., et al. "Developmental decline in height growth in Douglas-fir." Tree Physiology (2007) Vol. 27, Iss. 3: 441-53. https://doi.org/10.1093/treephys/27.3.441.
51 Greenwood, M.S. and K.W. Hutchison. "Maturation as a Developmental Process." In: Ahuja, MR. and W.J. Libby (editors) Clonal Forestry I. Springer (1993) pp. 14-33 https://doi.org/10.1007/978-3-642-84175-0_3.
52 *Id.*
53 Coder, K. D. "Tree Sex: Gender & Reproductive Strategies." Warnell School of Forestry and Natural Resources at the University of Georgia (2008). https://esploro.libs.uga.edu/esploro/outputs/report/Tree-sex-Gender-and-reproductive-strategies/9949316161802959; Hackett, W.P., "Juvenility, Maturation, and Rejuvenation in Woody Plants." In: Janick, J. (editor) Horticultural Reviews vol. 7 (1985) pp. 109-146. https://doi.org/10.1002/9781118060735.ch3.
54 Nor would the rulemaking preclude logging of younger trees, enabling federal forests to continue to supply timber to the market. Additionally, non-federal lands, which supply more than 95% of timber used in the U.S., would be unaffected by the rule. Kerr, A. "The Contribution of Federal Logs to the Nation's Wood Consumption." The Larch Company (2021).
https://static1.squarespace.com/static/573a143a746fb9ea3f1376e5/t/6058bc1668cbb360610cb4a9/1616428055018/FederalTimberSupplyLarch.pdf.
55 Brandt, P. et al. "Multifunctionality and biodiversity: Ecosystem services in temperate rainforests of the Pacific Northwest, USA." Biological Conservation (2014) Vol. 169: 362–371. https://doi.org/10.1016/j.biocon.2013.12.003.
56 Johnson, D. L., J. F. Franklin, and K. N. Johnson. "Ecological Forest Management," Waveland Press (2018).

As discussed in more detail below, the benefits of this complexity are readily borne out in the places where mature forests and trees have been allowed to develop. For example, research comparing national forests and predominantly Ojibwe and Menominee forests in Wisconsin found that the latter, which were older than the former, showed consistently larger tree volume, more overall plant diversity (including understory), fewer invasive species, and greater species diversity due in part to the intentional preservation of mature and old-growth trees.[57] Additionally, research in Maine suggested that larger trees are better able to withstand natural disturbances and are, consequently, more resilient to climate change.[58]

Critically, "[t]he developmental sequence is primarily one that consists of gradual changes that take place over long periods of time (e.g., decades)," rather than all at once.[59] By 80 years, many forests will likely have at least some of the key ecological features that scientists have identified in various mature forests.[60] Given that such little old growth remains, setting protections at this age is a highly efficient way to ensure both the full development of these and other ecologically critical features and the hastened recovery of key ecological processes.

a. Mature Forest Structural Complexity

As noted above, as forests mature, they develop a complex structural arrangement. Large trees (dead and alive), understory plants, and the organic soil layer (top soil horizons) all contribute to this complexity.[61] Structure accumulates in the form of, for instance, snags and CWD, cavities in trees created by branch breakage or by animal activity (e.g., woodpeckers), the horizontally complex understory arrangement of foliage, and crown layering and upper branching patterns.

This mature structure begets biodiversity and ecosystem functions. The above-ground structure creates numerous habitat opportunities. For instance, many raptors nest and perch at the top of the tallest trees with complex branching patterns or broken tops where nests can be positioned as platforms. In coastal mature ecosystems, moss and lichens accumulate thick layers on canopy branches, providing a micro-ecosystem within the forest ecosystem that is populated by numerous epiphytes, mollusks, salamanders, and tree voles that can live out their entire existence in a single mature tree. Woodpeckers also feed and drill cavities into live and dead trees for nesting and foraging, which in turn, opens niche space for other cavity nesting species that cannot drill their nest holes (many songbirds, bats, and small mammals).

Below ground structure in mature forests is centered on the upper soil horizons that develop from decades or centuries of decomposition of CWD. This part of the soil accumulates carbon, nitrogen, and other essential nutrients, creating habitat opportunities for myriad invertebrates involved in

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[57] Waller, D. M., and N. J. Reo. 2018. "First Stewards: Ecological Outcomes of Forest and Wildlife Stewardship by Indigenous Peoples of Wisconsin, USA." Ecology and Society (2018) Vol. 23, Iss. 1. https://doi.org/10.5751/ES-09865-230145.

[58] Fien, E. K. et al. "Drivers of Individual Tree Growth and Mortality in an Uneven-Aged, Mixed-Species Conifer Forest." Forest Ecology and Management (2019) Vol. 449. https://doi.org/10.1016/j.foreco.2019.06.043.

[59] Johnson, D. L., J. F. Franklin, and K. N. Johnson. "Ecological Forest Management," Waveland Press (2018).

[60] Franklin, J. F. et al. "Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example," Forest Ecology and Mgmt (2002) Vol. 155, Iss. 1-3, pp. 399-423. https://doi.org/10.1016/S0378-1127(01)00575-8.

[61] Johnson, D. L., J. F. Franklin, and K. N. Johnson. "Ecological Forest Management," Waveland Press (2018). Perry, D. A. "Forest ecosystems." JHU Press (1994). https://books.google.com/books/about/Forest_Ecosystems.html?id=ZWNtHLz3fXYC.

nutrient cycling. In fact, the richness of invertebrates in soils of mature temperate forests is significant and much greater than that in the tropical regions.[62]

Another critical below-ground function of older forests is mycorrhizae support. "All forest trees form mycorrhizae involving thousands of fungal species"[63] that form an underground chemical/nutrient "highway" with connections strongest for trees within the same cohort (a clustering of large trees) and same species (particularly the progeny of older trees). Further, "[m]ycorrhizal fungi can link the roots of different plant hosts, forming mycorrhizal networks."[64] When large trees are selectively cut down from within large tree cohorts this can impair the entire cohort by breaking the network linkages.[65] These networks link trees of the same and different species of varying age classes, but older trees serve as hubs, facilitating the transfer of water, carbon, nutrients, and compounds that act in a similar fashion as neurotransmitters enabling chemical communication.[66] Preserving these hub trees is essential for the functionality of mature and old-growth forests.

Mature and old-growth forests also provide critical connections to other ecosystems. A large tree that dies and falls into a stream, for instance, will become hiding and spawning cover for fish and other aquatic organisms. The post-spawning death of salmon, in return, then provides nutrients via decomposition for uptake by large trees in riparian areas. As noted above, by 80 years many forests will have developed these and other ecological functions and they will continue to develop complexity as they age toward old growth.

b. Biodiversity

Mature and old-growth forests maintain unique and complex biodiversity across all forest types, from the coast redwoods and Alaska's temperate rainforest, to the dry pine/mixed conifers of the intermountain and southwest, the massive Hartwick pines and beach-maple forests of the Great Lakes, the northern hemlock-fir stands of New England, the mixed hardwoods of Appalachia, and on to the long-leaf pine and bottomland cypress swamps of the deep south. Native species richness

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[62] Porazinski, D. L. et al., "Nematode Spatial and Ecological Patterns from Tropical and Temperate Rainforests." PLOS ONE (2012). https://doi.org/10.1371/journal.pone.0044641; DellaSala, D. A. "Temperate and Boreal Rainforests of the World." Island Press (2011). https://link.springer.com/book/10.5822/978-1-61091-008-8.

[63] Simard S.W. et al. "Meta-networks of fungi, fauna and flora as agents of complex adaptive systems." In: Puettmann K., Messier, C., Coates K. (editors) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge (2013) pp. 133–164. https://www.researchgate.net/publication/282661300_Meta-networks_of_fungi_fauna_and_flora_as_agents_of_complex_adaptive_systems.

[64] Simard, S. W. "Mycorrhizal networks facilitate tree communication, learning and memory." In: Baluska, F., Gagliano M., Witzany, G. (editors) Memory and Learning in Plants. Springer (2018) pp. 191-213. https://doi.org/10.1007/978-3-319-75596-0_10.

[65] Simard S.W. et al. "Meta-networks of fungi, fauna and flora as agents of complex adaptive systems." In: Puettmann K., Messier, C., Coates K. (editors) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge (2013) pp. 133–164. https://www.researchgate.net/publication/282661300_Meta-networks_of_fungi_fauna_and_flora_as_agents_of_complex_adaptive_systems.

[66] Simard, S. W. "The foundational role of mycorrhizal networks in self organization of interior Douglas-fir forests." Forest Ecology and Management (2009) Vol. 258: S95–S107.https://doi.org/10.1016/j.foreco.2009.05.001; Simard, S. W. et al. "Mycorrhizal networks: mechanisms, ecology and modeling." Fungal Biology Review (2012) Vol. 26, Iss. 1: 39–60. https://doi.org/10.1016/j.fbr.2012.01.001; Simard, S. W. "Mycorrhizal networks facilitate tree communication, learning and memory." In: Baluska, F., Gagliano M., Witzany, G. (editors) Memory and Learning in Plants. Springer (2018) pp. 191-213. https://doi.org/10.1007/978-3-319-75596-0_10; Simard, S. W. et al. "Partial Retention of Legacy Trees Protect Mycorrhizal Inoculum Potential, Biodiversity, and Soil Resources While Promoting Natural Regeneration of Interior Douglas-Fir." Frontiers in Forests and Global Change (2021) Vol. 3. http://dx.doi.org/10.3389/ffgc.2020.620436.

and abundance in these and other ecosystems tends to reach its highest levels on both ends of the successional cycle – in complex early seral forests (a mature forest that has experienced mixed to high burn severity and is re-establishing itself)[67] and old growth forest that is undisturbed. It is in mature forests that the biodiversity seen in old-growth forests begins to rebuild itself.

Mature and old-growth forests also play a key role as regional climate refugia for a wide variety of species. As an example, several of the biodiversity hotspots and ecoregions highlighted by the World Wildlife Fund (WWF) and Conservation International (CI)[68] feature important US mature and old-growth forests, including these:

- Klamath-Siskiyou (northwest California, southern Oregon): This area is considered one of the world's most biodiverse temperate conifer forest ecoregions with an exceptional richness of endemic mollusks, endemic plants, conifers, and other highly rich taxa. This ecoregion is considered endangered due to logging, roads, and other developments impacting older forests as well as postfire logging of complex early successional forests.

- Long-leaf pine wiregrass (Florida): While only about 2% remains as mature, this highly endangered ecosystem is one of the most biodiverse temperate forests (mainly the understory, which is maintained by large trees and periodic fire) in the world.

- Blue Ridge Mountains and Appalachia Mixed Mesophytic Forests: This area features an exceptional diversity of amphibians, neotropical migratory birds, and plant species. It has been highly altered by logging and development, but these forests are maturing and developing old-growth characteristics.

i. <u>Threatened, Endangered, and Sensitive Species</u>

In addition to the general biodiversity benefits of mature and old-growth forests, they provide essential safe havens for many threatened, endangered, and sensitive species in federal forests. Some examples include:

- Spotted owl (the northern and Mexican subspecies are federally listed as threatened, and the Fish and Wildlife Service is preparing a 12-month finding for the California Spotted Owl): Spotted owls need mature and old-growth forests for nesting and roosting, and, in the Pacific Northwest, for withstanding invasive barred owl invasions. They serve as an "umbrella" or "flagship" species for thousands of older-forest-associated species. When these older forests are logged, including by reducing canopy levels via thinning and fuel reduction treatments, Northern spotted owls are forced to compete with barred owls.[69] Additionally, studies have found that any reduction in canopy cover by logging harms

[67] Swanson, M. E. et al. "The forgotten stage of forest succession: early-successional ecosystems on forest sites." Frontiers in Ecology and Environment (2011) Vol. 9, Iss. 2: 117-125. https://doi.org/10.1890/090157; DellaSala, D. A. and C. T. Hanson. "The ecological importance of mixed-severity fires: nature's phoenix." Elsevier (2015). https://www.elsevier.com/books/the-ecological-importance-of-mixed-severity-fires/dellasala/978-0-12-802749-3.
[68] Ricketts, T.H. et al., "Terrestrial Ecoregions of North America: A Conservation Assessment." Island Press (1999); Myers, N. et al. "Biodiversity hotspots for conservation priorities." Nature (2000) Vol. 403: 853–858. https://doi.org/10.1038/35002501.
[69] Dugger, K. M. et al. "The effects of habitat, climate, and Barred Owls on long-term demography of Northern Spotted Owls." The Condor (2016) Vol. 118: 57-116. http://dx.doi.org/10.1650/CONDOR-15-24.1.

spotted owls by negatively impacting site occupancy, reproduction, and survival.[70] These impacts from logging can be dramatic within just a few years. Indeed, based on modeling studies, the rate of old forest loss from proposed thinning in the Northern spotted owl recovery plan exceeds the anticipated loss of nesting and roosting habitat from fires over a 40-year period, even with climate change in the model.[71]

- Marbled murrelet (federally listed as threatened): This is a coastal seabird that nests in old-growth forests found along the Pacific coast. Logging these forests fragments older forests' nesting areas, which then results in elevated nest predation by corvids.[72]

- Kaibab squirrel (Arizona state listed as imperiled and vulnerable): This is an endemic and rare subspecies of tassel-eared squirrel found only on Arizona's Kaibab Plateau. It depends on the structure and complex interactions of old-growth forests to facilitate its movements and provide food.[73]

- Canada lynx (federally listed as threatened): This elusive cat species depends on complex, multistory forests for denning habitat and to find its main prey species: snowshoe hares. This type of high-quality denning habitat is limited to mature forest, which provides the coarse woody debris needed for thermal cover and protection for the lynx's young.[74]

- Fisher (federally listed as sensitive): This is a medium mustelid that can be found in the northern Rockies, primarily Montana and Idaho. Research shows that fishers are

[70] Blakesley, J.A. et al. "Site Occupancy, Apparent Survival, And Reproduction Of California Spotted Owls In Relation To Forest Stand Characteristics," Journal of Wildlife Management (2005) Vol. 69, Iss. 4: 1554-1564. https://doi.org/10.2193/0022-541X(2005)69[1554:SOASAR]2.0.CO;2; Seamans, M. E. and R.J. Gutiérrez. "Sources of variability in spotted owl population growth rate: testing predictions using long-term mark-recapture data." Oecologia (2007) Vol. 152, Iss. 1: 57-70. https://doi.org/10.1007/s00442-006-0622-x; Stephens, S.L. et al., "California Spotted Owl, Songbird, and Small Mammal Responses to Landscape Fuel Treatments," BioScience (2014) Vol. 64, Iss. 10: 893–906. https://doi.org/10.1093/biosci/biu137; Tempel, D. J., et al., "Effects of forest management on California Spotted Owls: implications for reducing wildfire risk in fire-prone forests." Ecological Applications (2014) Vol. 24: 2089-2106. https://doi.org/10.1890/13-2192.1; Tempel, D. et al. "Meta-analysis of California Spotted Owl (Strix occidentalis occidentalis) territory occupancy in the Sierra Nevada: Habitat associations and their implications for forest management." The Condor (2016) Vol. 118: 747-765. https://doi.org/10.1650/CONDOR-16-66.1; Stephens, S. L., et al. "California Spotted Owl, Songbird, and Small Mammal Responses to Landscape Fuel Treatments." BioScience, (2014) Vol. 64, Iss. 10: 893–906. https://doi.org/10.1093/biosci/biu137; Tempel, D. J. et al., "Effects of forest management on California Spotted Owls: implications for reducing wildfire risk in fire-prone forests." Ecological Applications (2014) Vol. 24, Iss. 8: 2089-2106. https://doi.org/10.1890/13-2192.1.
[71] Odion, D.C. et al. "Effects of Fire and Commercial Thinning on Future Habitat of the Northern Spotted Owl." The Open Ecology Journal (2014) Vol. 7: 37-51. http://dx.doi.org/10.2174/1874213001407010037.
[72] Herbert, P. N. and R. T. Golightly. "Observations of predation by corvids at a marbled murrelet nest." Journal of Field Ornithology (2007) Vol. 78, Iss. 2. https://doi.org/10.1111/j.1557-9263.2007.00105.x; Malt, J. M. and D. B. Lank. "Marbled murrelet nest predation risk in managed forest landscapes: dynamic fragmentation effects at multiple scales." Ecological Applications (2009) Vol. 19, Iss. 5: 1274-1287. https://doi.org/10.1890/08-0598.1.
[73] Dodd, N. L. et al. "Tassel-Eared Squirrel Population, Habitat Condition, and Dietary Relationships in North-Central Arizona." Journal of Wildlife Management (2003) Vol. 67, Iss. 3, pp. 622-633. https://doi.org/10.2307/3802719; Loberger, C. D. et al. "Use of restoration-treated ponderosa pine forest by tassel-eared squirrels." Journal of Mammalogy (2011) Vol. 92, Iss. 5, pp. 1021-1027. https://doi.org/10.1644/10-MAMM-A-321.1.
[74] Koehler, G. M., and K. B. Aubry. "Lynx." In: Ruggiero, L. F., Aubry, K. B., Buskirk, S. W., Lyon L. J., Zielinkski W. J. (editors) The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine in the western United States. General Technical Report RM-254. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station (1994). https://www.fs.usda.gov/rm/pubs_rm/rm_gtr254.pdf.

associated with older forests throughout their range.[75] Fishers need dense overhead cover, abundant coarse woody debris, and large trees.[76] Female fishers use cavities in large-diameter live trees and snags because tree cavities regulate temperatures and protect kits from predators.[77] Forest configuration figures just as much into the type of habitat that fisher need as composition, specifically the proximity of mature forest patches. Sauder and Rachlow 2014 found that fishers in Idaho's Clearwater Basin used landscapes with large patches of mature forest arranged in connected patterns.[78]

- Pacific (formerly American or Pine) marten (Coastal distinct population (NW California and SW Oregon) federally listed as sensitive; Vermont state listed as endangered): The marten is a mustelid species that has been eliminated from much of its historic range. According to the Fish and Wildlife Service, "[m]artens across North America generally select older forest stands that are structurally complex (e.g., late-successional, old-growth, large-conifer, mature, late-seral). These forests generally have a mixture of old and large trees, multiple canopy layers, snags and other decay elements, dense understory, and have a biologically complex structure and composition."[79] As mature and old-growth forests are lost, martens decline. "Pine" marten are on the State of Vermont Endangered Species List, and one of only two viable populations in the state is located within the Green Mountain National Forest. A 2022 study analyzing marten populations in Maine found that "even partial harvest activities can diminish the canopy cover, structural complexity and overall basal area [that marten] require[.]"[80] The same study found that "Marten…showed lower initial occupancy probability in areas of increasingly disturbed forest and had both higher extinction rates and lower colonization rates in these areas."[81]

- Northern long-eared bat (federally listed as threatened, proposed for uplisting to endangered): The bat depends on mature and old forests for roosting and foraging.[82] Its

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[75] Aubry, K. B. et al. "Meta-Analysis of Habitat Selection by Fishers at Resting Sites in the Pacific Coastal Region." The Journal of Wildlife Management (2013). Vol. 77, Iss. 5: 965-974. http://dx.doi.org/10.1002/jwmg.563; Olson, L. E. et al. "Modeling the effects of dispersal and patch size on predicted fisher (Pekania [Martes] pennanti) distribution in the U.S. Rocky Mountains." Biological Conservation (2014) Vol. 169: 89-98. https://doi.org/10.1016/j.biocon.2013.10.022; Sauder, J. D. and J. L. Rachlow. "Both forest composition and configuration influence landscape-scale habitat selection by fishers (Pekania pennanti) in mixed conifer forests of the Northern Rocky Mountains." Forest Ecology and Management (2014) Vol. 314: 75-84. http://dx.doi.org/10.1016/j.foreco.2013.11.029; Weir, R. D. and F. B. Corbould. "Factors affecting landscape occupancy by fishers in North-central British Columbia." Journal of Wildlife Management (2010) Vol. 74, Iss. 3: 405-410. https://doi.org/10.2193/2008-579.

[76] *Id.*

[77] *Id.*

[78] Sauder, J. D. and J. L. Rachlow. "Both forest composition and configuration influence landscape-scale habitat selection by fishers (Pekania pennanti) in mixed conifer forests of the Northern Rocky Mountains." Forest Ecology and Management (2014) Vol. 314: 75-84. http://dx.doi.org/10.1016/j.foreco.2013.11.029.

[79] U.S. Fish & Wildlife Service. Designation of Critical Habitat for the Coastal Distinct Population Segment of the Pacific Marten, 86 Fed. Reg. 58,831, 58,833 (Oct. 25, 2021) (proposed rule). https://www.federalregister.gov/documents/2021/10/25/2021-22994/endangered-and-threatened-wildlife-and-plants-designation-of-critical-habitat-for-the-coastal.

[80] Evans, B. E. and A. Mortelliti, "Effects of forest disturbance, snow depth, and intraguild dynamics on American marten and fisher occupancy in Maine, USA." Ecosphere (2022) Vol. 13, Iss. 4. https://doi.org/10.1002/ecs2.4027.

[81] *Id.*

[82] Burkhart, J. et al. "Species Status Assessment Report for the Northern long-eared bat (Myotis septentrionalis)," U.S. Fish and Wildlife Service. (2022) Version 1.1. https://www.fws.gov/sites/default/files/documents/Species%20Status%20Assessment%20Report%20for%20the%20Northern%20long-eared%20bat-%20Version%201.1%20%282%29.pdf.

> preferred roosting habitat is large-diameter live or dead trees of a variety of species, with exfoliating bark, cavities, or crevices. And its preferred foraging habitat is old forest with complex vertical structure on hillsides and ridges.[83]

c. Hydrological Function

Mature and old-growth forests play several key roles that help improve watershed integrity. Hammond notes that

> The highest quality water, provided in adequate and manageable quantities throughout an annual cycle is produced by old/old-growth forests. The multi-layered, large canopies, canopy gaps, and accumulations of decayed fallen trees provide for effective, natural water management that benefits forest ecosystems and aquatic ecosystems, and provides for human needs and safety. In short, old-growth forests are Nature's water storage and filtration system.[84]

Protecting forests and trees from logging at 80 years of age helps ensure that these and other hydrological co-benefits of the remaining older forests on federal lands are safeguarded, which is especially important for climate resilience. Logging these forests, particularly their larger trees, on the other hand, has significant deleterious effects on watershed integrity.

The bigger, older trees that form the core of mature and old-growth forests play an important part in the hydrological cycle. Forests generally circulate precipitation via uptake of water from roots to canopies and release water back to the atmosphere by evapotranspiration leakage through leaf pores. This function of trees increases as trees get older and bigger because leaf area is related to site water balance and soil water storage/retention, and larger trees have more leaf area and greater water balance.[85]

Mature and old-growth forests also help reduce flooding by buffering streams from peak high flows by arresting runoff through absorption and slow release of water. The complex structure of mature and old-growth forests, including large trees, downed wood, and pit-and-mound micro-topography, is exceptional at slowing, sinking, and storing water compared to heavily managed or younger forests. They also provide shade along riparian areas that keep stream and ambient temperatures from overheating. The older and larger the trees, the greater the watershed integrity benefits.

Additionally, the complex canopies associated with mature and old-growth forests help regulate the rate at which moisture and heat are exchanged with the atmosphere, which in turn influences water retention and the makeup of forest ecosystems. In the temperate zone, logging large canopy trees results in drier conditions, because the amount of sunlight and heat reaching the ground can cause more evaporative losses and higher surrounding temperatures.[86] Logging and development are also

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[83] *Id.*

[84] Hammond, H. "Submission to Old-Growth Strategic Review." (2020) https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/old-growth-forests/written-submissions/128_herb-hammond.pdf.

[85] Grier, C. G. and S. W. Running. "Leaf Area of Mature Northwestern Coniferous Forests: Relation to Site Water Balance." Ecology (1977) Vol. 58, Iss. 4. https://doi.org/10.2307/1936225.

[86] Wheeling, K. "How forest structure influences the water cycle." Eos (2019) Vol. 100. https://doi.org/10.1029/2019EO134709; Perry, T.D. and J. A. Jones, "Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA." Ecohydrology (2017) Vol. 10, Iss. 2: 1-13. https://doi.org/10.1002/eco.1790.

known to produce downwind continental interiors with declining rainfall and water availability that heighten drought and wildfire risks.[87]

Older forests are also essential for maintaining water balance in forested watersheds.[88] Analysis of 60-year records of daily streamflow from eight paired-basins in the Pacific Northwest showed how conversion of old-growth forests to Douglas-fir plantations reduced stream flow by 50%. This is because young trees have less ability to limit evapotranspiration, especially during dry summer months. Additionally, researchers noted that reduced summer streamflow in headwater basins with forest plantations may limit aquatic habitat and exacerbate stream warming, while altering water yield and timing of peak flows in larger basins.[89] Even though removing forest cover can temporarily accelerate the rate that precipitation becomes streamflow,[90] increases in flow rate and volume are typically short-lived, and the practice can ultimately degrade water quality and increase vulnerability to flooding for extended periods.

The hydrological importance of intact mature and old-growth forests also extends underground due to the way mycorrhizal networks transport water for germination and seedling survival. Researchers have found that hydraulic redistribution along the mycorrhizal network is an important adaptation that increases survival within dry-type forests.[91] In particular, research shows that the germination and survival of seedlings linked into the network of older Douglas-fir trees was substantially greater in a very dry climate compared to a wet climate due to the transfer of water to the new germinants. In the dry climate especially, the mycorrhizal network appeared to extend the niche breadth of interior Douglas-fir seedlings.[92] Removal of older trees that serve as hubs directing the flow of water and nutrients could significantly disrupt this network.

More broadly, unlogged watersheds with older forests and dense riparian vegetation are more hydrologically functional and contain higher levels of terrestrial and aquatic biodiversity, as the following examples illustrate:[93]

- In the Pacific Northwest, relatively high biodiversity in riparian forests is attributed to cool moist conditions, high productivity, and complex structural conditions present in older streamside forests. Notably, old-growth Douglas-fir stands generally contain abundant

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[87] Ellison, D. et al. "Trees, forests and water: Cool insights for a hot world." Global Environmental Change (2017) Vol. 43: 51-61. https://doi.org/10.1016/j.gloenvcha.2017.01.002.
[88] Jjang, Y. et al. "Linking tree physiological constraints with predictions of carbon and water fluxes at an old-growth coniferous forest." Ecosphere (2019) Vol. 10, Iss. 4. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecs2.2692.
[89] Perry, T.D. and J. A. Jones, "Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA." Ecohydrology (2017) Vol. 10, Iss. 2: 1-13. https://doi.org/10.1002/eco.1790.
[90] Rhodes, J. and C.A. Frissell. ""The High Costs and Low Benefits of Attempting to Increase Water Yield by Forest Removal in the Sierra Nevada." Report prepared for Environment Now (2016). http://dx.doi.org/10.13140/RG.2.1.1893.9926.
[91] Simard, S. W. et al. "Mycorrhizal networks: mechanisms, ecology and modeling." Fungal Biology Review (2012) Vol. 26, Iss. 1: 39–60. https://doi.org/10.1016/j.fbr.2012.01.001; Simard, S. W. "Mycorrhizal networks facilitate tree communication, learning and memory." In: Baluska, F., Gagliano M., Witzany, G. (editors) Memory and Learning in Plants. Springer (2018) pp. 191-213. https://doi.org/10.1007/978-3-319-75596-0_10.
[92] Simard S.W. et al. "Meta-networks of fungi, fauna and flora as agents of complex adaptive systems." In: Puettmann K., Messier, C., Coates K. (editors) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge (2013) pp. 133–164. https://www.researchgate.net/publication/282661300_Meta-networks_of_fungi_fauna_and_flora_as_agents_of_complex_adaptive_systems.
[93] Harr, R. D. "Fog drip in the Bull Run Municipal Watershed, Oregon." Journal of the American Water Resources Assoc. (1982) Vol. 18, Iss. 5: 785-789. https://doi.org/10.1111/j.1752-1688.1982.tb00073.x.

populations of epiphytic lichens and bryophytes that increase the canopy water storage in forests.[94] Further, logging has lasting impacts on evapotranspiration, water interception, snowmelt, flow routing, and streamflow that were still evident more than 50 years after clearcutting old-growth forests.[95] Large logs in old-growth forests also intercept 2–5% of the canopy through-fall to the forest floor and that, too, may affect the hydrological cycle when forests are logged in this region.[96] Additionally, dense riparian vegetation helps regulate the amount of sediment that reaches streams, depending on geomorphology.

- In eastern Oregon and Washington, the largest risk of accelerated erosion occurred from fuels reduction projects that included road construction, fuel breaks, postfire logging, and thinning.[97]

- In western Washington, the amount of large woody debris (LWD) surveyed in 70 stream reaches flowing through old-growth, clear-cut, and second-growth forests was greatest at old-growth sites.[98] Changes in LWD amount, characteristics, and function occurred very rapidly following logging.[99]

- In the coast redwood zone, standard rain gauges installed in open areas where fog is common collected up to 30 percent less precipitation than in old-growth forests.[100] Researchers noted that long-term logging in the watershed could reduce annual water yield and, more importantly, summer stream flow by reducing fog drip.

- In the southeastern United States, logging resulted in "increased stream sediment and nutrients, more variable flow, altered [fish and wildlife] habitat and stream and riparian communities, and increased risk of human health effects" from floods.[101] Importantly, the threshold for disturbance of the hydrological cycle can be quite low in this region, and impacts from altered hydrological cycles may extend to other humid regions.[102]

- In the southern Appalachian Highlands, forest cover helps stabilize the landscape and prevent landslides "by intercepting precipitation, increasing evapotranspiration, and

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[94] Pypker, T. G. et al. "The role of epiphytes in rainfall interception by forests in the Pacific Northwest. I. Laboratory measurements of water storage." Canadian Journal of Forest Research (2006) Vol. 36, Iss. 4. https://doi.org/10.1139/x05-298; Crampe, E. A. et al. "Fifty years of runoff response to conversion of old-growth forest to planted forest in the H. J. Andrews Forest, Oregon, USA." Hydrological Processes (2021) Vol 35, Iss. 5. https://doi.org/10.1002/hyp.14168.

[95] Crampe, E. A. et al. "Fifty years of runoff response to conversion of old-growth forest to planted forest in the H. J. Andrews Forest, Oregon, USA." Hydrological Processes (2021) Vol 35, Iss. 5. https://doi.org/10.1002/hyp.14168.

[96] Harmon, M. E. and J. Sexton. "Water balance of conifer logs in early stages of decomposition." Plant and Soil (1995) Vol. 172: 141-152. https://doi.org/10.1007/BF00020868.

[97] Wondzell, S. M.. "The influence of forest health and protection treatments on erosion and stream sedimentation in forested watersheds of Eastern Oregon and Washington." Northwest Science (2001) Vol. 75: 128-140. https://research.libraries.wsu.edu/xmlui/handle/2376/989.

[98] Bilby, R. E. and J. W. Ward. "Characteristics and Function of Large Woody Debris in Streams Draining Old-Growth, Clear-Cut, and Second-Growth Forests in Southwestern Washington." Canadian Journal of Fisheries and Aquatic Sciences (1991) Vol. 48, Iss. 12: 2499-2508. https://doi.org/10.1139/f91-291.

[99] *Id.*

[100] Harr, R. D. "Fog drip in the Bull Run Municipal Watershed, Oregon." Journal of the American Water Resources Assoc. (1982) Vol. 18, Iss. 5: 785-789. https://doi.org/10.1111/j.1752-1688.1982.tb00073.x.

[101] Nagy, R.C., et al. "Water resources and land use and cover in a humid region: the southeastern United States." J. Environmental Quality. (2011) Vol. 40, Iss. 3: 867-878. https://doi.org/10.2134/jeq2010.0365.

[102] *Id.*

reinforcing roots."[103] Logging, on the other hand, increases the frequency of landslides for a given storm event. Climate change that results in increased occurrences of high-intensity rainfall through more frequent storms, or higher-intensity storms, would also be expected to exacerbate this effect.

- In the Mid-Atlantic and northeastern states, mature forests play a key role in maintaining forested watersheds. Logging them makes these watersheds vulnerable to disturbance and fragmentation.[104]

- In the eastern United States, the decimation of older forests and concomitant effect on watershed integrity continues to reverberate. After Tropical Storm Irene, Vermont's Department of Forests, Parks, and Recreation found that "[t]he quality of [today's] forests is not the same as the pre-Settlement old growth forests. The legacy of early landscape development and a history of channel and floodplain modifications continue to impact water and sediment routing from the land."[105] The results of this landscape history include reductions in ecosystem services like water filtration. For example, phosphorus, a nutrient that impairs many U.S. water bodies and drives harmful algal blooms, is much more effectively removed from ecosystems by mature and old forests.[106]

- Intact forested watersheds present in inventoried roadless areas, which have a greater composition of mature trees and where logging is generally prohibited, tend to be at the headwaters of streams with the cleanest drinking water source areas.[107]

IV. <u>Conclusion</u>

We thank you for inviting our input. We appreciate the effort to define mature and old-growth forests for certain purposes and in the task of inventorying them. We strongly urge the BLM and Forest Service not to let that work delay the urgent, parallel challenge of ensuring that the logging they authorize no longer makes the climate crisis worse by degrading or destroying carbon reserves in mature stands and trees.

For purposes of a much-needed regulation ending such logging, 80 years is a straightforward metric for maturity. It can be readily operationalized in the field with reliable results, will protect the bulk of above-ground carbon sequestration and storage in federal forests, accords with a variety of indicia of

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[103] Wooten, R. M. et al., "Frequency and Magnitude of Selected Historical Landslide Events in the Southern Appalachian Highlands of North Carolina and Virginia: Relationships to Rainfall, Geological and Ecohydrological Controls, and Effects." In: Greenberg, C., Collins, B. (editors) Natural Disturbances and Historic Range of Variation. Springer (2016) pp. 203-262. https://doi.org/10.1007/978-3-319-21527-3_9.
[104] Schaberg, R. H. and R. C. Abt. "Vulnerability of Mid-Atlantic Forested Watersheds to Timber Harvest Disturbance." Environmental Monitoring and Assessment (2004) Vol. 94, 101-113. https://doi.org/10.1023/B:EMAS.0000016882.72472.e1; Hayes, B. R. et al. "Legacy of Historic Logging on Mid-Atlantic and New England Streams and Riparian Corridors; Experimental Approaches to Improving Aquatic Health and Ecosystem Function." American Geophysical Union Fall Meeting (2019). https://ui.adsabs.harvard.edu/abs/2019AGUFM.H33J2063H/abstract.
[105] Underwood, K. L. and D. Brynn. "Enhancing Flood Resiliency of Vermont State Lands." Vermont Forests, Parks & Recreation (2015). https://familyforests.org/wp-content/uploads/2018/08/SLFR-final-report-2015June30.pdf.
[106] Warren, D. R. et al. "Forest Stream Interactions in Eastern Old-Growth Forests." In: Barton, A.M., Keeton, W.S. (editors) Ecology and Recovery of Eastern Old-Growth Forests. Island Press (2018) pp. 159-178. https://doi.org/10.5822/978-1-61091-891-6_9.
[107] DellaSala, D. A. et al. "Roadless areas and clean water." Journal of Soil and Water Conservation (2011) Vol. 66, Iss. 3: 78A-84A. https://doi.org/10.2489/jswc.66.3.78A.

biological maturity, and secures significant co-benefits of national importance. A regulation using that threshold as a carbon safety net under logging authorizations would not prevent individual federal forests from adopting more stringent standards based on local conditions. Nor would it interfere with appropriate fire risk reduction and ecological restoration work. Over-riding considerations could be accommodated with carefully tailored exceptions.

As the federal government works to fulfill our country's pledge to reduce net greenhouse gas emissions 50-52% by 2030, this is a simple, highly effective, and immediately available measure we cannot fail to implement. And doing so will reap additive benefits by setting a global example and helping to reaffirm American leadership in the fight to keep climate change within tolerable limits. Please do not fail to initiate a protective rulemaking now that will safeguard our public forests' important carbon resources from loss through discretionary logging.

Sincerely,

Climate Forests Campaign Coordinating Group (Center for Biological Diversity, Earthjustice, Environment America, Natural Resources Defense Council, Sierra Club, Oregon Wild, Standing Trees, The Larch Company, Wild Heritage, WildEarth Guardians)

Appendix 1 – Comparison of carbon stocks in various national forests

Dr. Richard Birdsey from the Woodwell Climate Research Center analyzed above-ground carbon stores in seven different national forests (or national forest groupings, where single forests did not provide enough plots) using FIA data. Selected data analyzed are reproduced with permission in Tables 2 - 7. The analysis below shows that a protective threshold of 80 years ensures conservation of significant amounts of stored aboveground carbon in forests from markedly different parts of the country. Table 1 and Figure 1 show the declining preservation of total aboveground live tree carbon stores as a lower age threshold for protection is increased. The analysis collectively shows that as the lower age limit for protection moves above 80, many forests see a significant drop-off in stored carbon protected.

Table 1. Comparison of proportion of total aboveground carbon in live trees preserved with increasing lower age limit

Lower limit age	Malheur NF	S. Appalachian NFs	Black Hills NF	Chequamegon-Nicolet NF	Gifford Pinchot NF	Green & White Mtn NFs
51	95%	95%	91%	86%	90%	95%
61	93%	91%	85%	79%	87%	89%
71	89%	84%	76%	66%	83%	76%
81	81%	69%	67%	48%	79%	52%
91	65%	45%	55%	26%	72%	25%
101	52%	23%	42%	13%	69%	9%
111	37%	11%	27%	6%	64%	5%

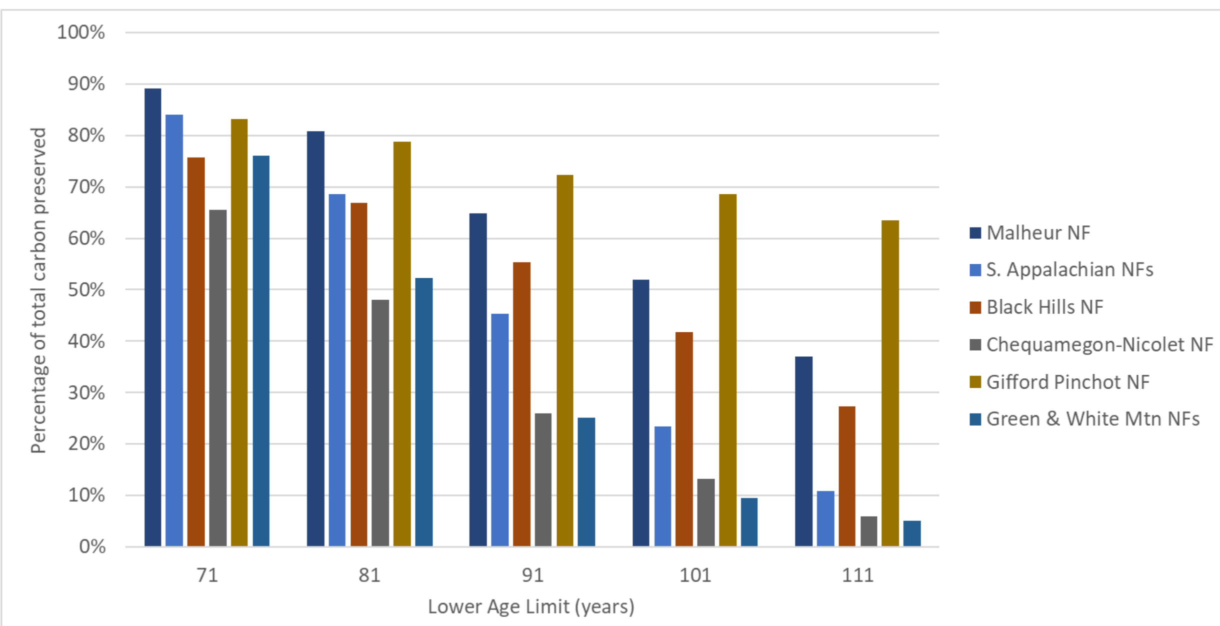

Figure 1. Declining preservation of aboveground live tree carbon with increasing lower age limit for protection for selected national forests

Table 2. Aboveground carbon in live trees (at least 1 inch diameter at breast height (d.b.h.)/diameter at root collar (d.r.c.)), in short tons, on unreserved forest land, all forest types, Southern Appalachian National Forests (Pisgah, Nantahala, Cherokee, Monongahela, Jefferson, George Washington)

	Stand age 10 yr classes																			
dbh/drc class: 2" to 41"	Total	0-10 years	11-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61-70 years	71-80 years	81-90 years	91-100 years	101-110 years	111-120 years	121-130 years	131-140 years	141-150 years	151-160 years	161-170 years	181-190 years	200+ years
Total	123,578,504	43,277	147,082	1,473,984	2,114,995	2,930,485	4,322,890	8,745,943	19,056,605	28,715,927	27,115,803	15,606,782	5,743,906	3,228,009	2,513,269	656,861	815,150	234,412	69,937	43,187
1.0-2.9	1,492,778	3,483	28,698	116,434	89,165	56,661	56,390	113,093	188,721	304,882	263,619	144,305	69,687	23,143	15,405	5,335	9,795	3,962	-	-
3.0-4.9	3,451,731	3,982	46,353	228,173	187,531	110,748	142,886	279,760	460,771	675,971	657,762	348,927	163,626	24,371	89,031	13,327	7,608	7,572	3,333	-
5.0-6.9	6,072,384	530	19,529	299,264	357,168	288,144	301,945	529,824	927,491	1,244,866	1,046,534	566,284	187,562	103,982	107,378	28,408	48,267	7,796	7,216	194
7.0-8.9	9,296,218	3,777	9,232	298,638	399,334	343,816	501,800	772,446	1,539,745	2,005,726	1,754,939	888,308	300,954	179,517	172,621	39,966	58,603	22,233	4,562	-
9.0-10.9	11,809,274	2,795	5,633	211,089	337,295	435,203	652,772	1,037,176	1,968,188	2,637,137	2,392,388	1,196,811	384,108	203,248	247,074	40,463	33,023	16,271	8,602	-
11.0-12.9	13,349,600	-	9,485	79,417	215,957	352,565	665,604	1,027,704	2,230,331	3,380,010	2,636,804	1,578,880	487,465	302,294	251,719	56,199	37,974	33,133	4,059	-
13.0-14.9	13,737,439	5,855	-	60,525	196,154	352,091	618,150	1,215,771	2,264,228	3,295,315	2,737,009	1,579,754	613,034	330,646	221,551	72,832	113,627	46,346	10,047	4,504
15.0-16.9	13,199,708	22,856	11,675	31,443	119,419	298,187	535,584	1,035,067	2,134,551	3,178,930	2,860,959	1,494,116	707,718	355,239	321,203	48,517	34,659	9,583	-	-
17.0-18.9	12,297,007	-	-	69,047	92,769	204,152	310,978	857,508	1,826,754	2,767,993	2,983,254	1,945,654	630,574	247,652	258,159	70,302	10,540	13,014	8,658	-
19.0-20.9	9,270,884	-	16,476	53,683	8,693	170,330	147,809	389,597	1,502,809	2,410,078	2,066,237	1,576,412	372,398	196,227	233,744	35,641	49,638	17,651	23,459	-
21.0-22.9	8,312,002	-	-	26,271	-	160,201	122,769	493,091	1,334,138	1,791,502	2,248,457	959,075	356,250	414,820	215,023	60,076	81,407	27,854	-	21,066
23.0-24.9	6,694,814	-	-	-	7,451	-	53,382	365,939	893,416	1,649,554	1,480,551	1,212,419	404,917	144,918	321,347	14,623	117,300	28,996	-	-
25.0-26.9	4,560,597	-	-	-	56,703	58,293	133,075	176,724	546,706	1,070,989	1,347,007	591,332	306,132	161,028	16,059	-	96,548	-	-	-
27.0-28.9	3,021,563	-	-	-	47,356	66,014	35,994	103,176	223,164	722,518	735,183	437,709	345,564	145,931	-	74,393	84,560	-	-	-
29.0-30.9	1,878,198	-	-	-	-	-	17,662	76,897	303,008	287,739	638,377	322,676	110,195	65,103	42,954	13,588	-	-	-	-
31.0-32.9	1,492,021	-	-	-	-	-	26,090	84,429	385,387	382,979	215,106	185,877	115,654	47,478	-	-	31,601	-	-	17,422
33.0-34.9	1,210,643	-	-	-	-	-	-	142,372	117,696	358,922	207,386	119,301	89,968	174,998	-	-	-	-	-	-
35.0-36.9	606,684	-	-	-	-	-	-	-	34,985	295,157	134,803	94,678	47,061	-	-	-	-	-	-	-
37.0-38.9	729,203	-	-	-	-	-	-	-	-	88,788	398,441	158,784	-	-	-	83,189	-	-	-	-
39.0-40.9	384,019	-	-	-	-	-	-	45,368	36,025	166,871	43,828	40,889	51,037	-	-	-	-	-	-	-
41.0+	711,737	-	-	-	-	34,081	-	-	138,489	-	267,159	164,591	-	107,416	-	-	-	-	-	-

Table 3. Aboveground carbon in live trees (at least 1 inch d.b.h./d.r.c.), in short tons, on unreserved forest land, all forest types, Gifford-Pinchot National Forest

	Stand age 10 yr classes																					
dbh/drc class: 2" to 41"	Total	0-10 years	11-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61-70 years	71-80 years	81-90 years	91-100 years	101-110 years	111-120 years	121-130 years	131-140 years	141-150 years	151-160 years	161-170 years	171-180 years	181-190 years	191-200 years	200+ years
Total	78,776,160	2,463	57,950	1,291,113	3,323,094	3,466,927	2,360,433	2,702,207	3,561,566	5,006,665	2,944,469	4,029,334	4,676,973	2,628,225	4,051,165	2,800,485	3,667,776	5,285,321	2,527,173	1,592,732	1,108,212	21,691,878
1.0-2.9	230,488	-	2,917	22,756	34,810	18,703	4,606	8,527	10,588	13,547	7,107	9,790	5,015	1,953	10,998	8,857	4,676	9,306	3,200	2,403	5,924	44,805
3.0-4.9	626,822	-	18,992	73,458	112,132	28,327	14,777	24,272	33,833	31,442	21,945	33,141	12,144	8,555	24,017	14,766	16,363	27,717	9,411	1,092	14,048	106,388
5.0-6.9	978,212	1,399	20,236	122,247	161,797	64,037	40,485	52,536	46,356	95,836	34,000	49,683	29,888	15,471	31,908	23,646	21,123	21,943	8,519	8,437	12,474	116,192
7.0-8.9	2,056,733	375	8,630	236,700	292,994	211,897	97,788	110,440	125,063	205,160	62,028	113,224	76,531	32,962	76,067	54,162	44,458	40,682	17,237	16,916	26,210	207,209
9.0-10.9	3,540,069	689	1,912	323,021	637,903	382,554	196,095	195,169	148,697	306,944	112,848	184,558	175,269	72,033	111,312	84,658	54,214	84,836	43,394	25,284	41,451	357,230
11.0-12.9	4,555,290	-	1,605	248,233	670,993	566,393	262,791	282,426	268,966	422,539	153,038	281,970	253,010	95,712	157,309	123,251	83,026	107,732	80,529	39,678	45,530	410,559
13.0-14.9	5,208,665	-	-	112,179	604,703	733,755	330,336	296,794	320,693	509,114	230,679	390,285	273,368	142,487	154,674	161,301	97,955	154,750	141,383	5,582	55,816	492,809
15.0-16.9	5,735,632	-	-	57,071	388,589	656,777	426,378	389,804	390,307	531,011	204,061	425,487	320,616	173,931	284,856	179,634	95,608	182,000	171,392	81,821	98,952	677,338
17.0-18.9	5,500,601	-	-	21,516	221,577	396,448	262,552	333,752	433,172	510,181	269,813	379,542	439,392	185,325	335,743	283,716	199,706	244,287	153,789	67,915	117,753	644,425
19.0-20.9	5,446,461	-	-	14,883	150,805	163,642	217,651	390,077	351,566	513,801	442,869	336,032	339,303	200,925	379,001	229,422	252,577	280,249	169,512	83,282	43,737	887,128
21.0-22.9	5,662,300	-	-	16,699	16,351	94,872	183,475	182,451	404,255	555,905	327,824	357,159	367,993	160,299	299,916	195,402	270,623	320,252	303,632	81,848	87,494	1,435,851
23.0-24.9	5,057,467	-	-	-	-	50,919	81,307	59,451	293,867	437,850	257,495	321,577	551,839	177,843	259,892	319,643	224,339	439,362	309,756	136,811	41,825	1,093,692
25.0-26.9	5,097,935	-	-	2,628	-	40,397	61,859	102,699	438,698	229,649	180,023	277,896	437,838	212,619	315,328	263,862	412,858	433,552	243,244	135,774	58,120	1,250,891
27.0-28.9	4,196,435	-	-	-	-	13,312	30,854	80,081	108,498	267,059	122,996	284,942	142,297	119,043	273,956	294,665	329,325	454,255	261,437	149,718	101,239	1,162,759
29.0-30.9	3,414,155	-	-	23,440	-	8,879	-	56,903	22,115	66,889	96,330	271,590	188,459	170,138	268,152	61,580	293,575	375,207	77,085	239,733	13,239	1,180,840
31.0-32.9	3,040,108	-	-	-	-	7,759	4,970	31,379	43,240	101,423	75,358	80,480	182,343	96,572	301,364	90,051	282,198	380,832	94,587	78,161	57,792	1,131,597
33.0-34.9	2,559,851	-	3,657	-	3,665	2,532	13,867	21,019	26,349	42,033	57,351	64,007	109,457	137,624	164,601	87,380	251,088	295,068	80,005	106,953	34,847	1,058,348
35.0-36.9	2,548,179	-	-	4,103	5,686	7,580	4,573	20,975	20,046	19,605	54,202	73,528	134,563	140,908	150,615	63,830	201,899	380,552	92,178	27,373	32,599	1,113,364
37.0-38.9	2,066,627	-	-	322	6,176	14,477	6,201	24,500	-	25,809	74,755	8,044	99,214	92,966	117,916	35,091	112,653	208,851	51,175	38,951	22,887	1,126,638
39.0-40.9	1,653,838	-	-	-	6,680	-	25,632	11,531	16,713	15,404	-	21,715	126,615	65,309	64,543	33,417	123,742	178,836	70,128	65,778	13,715	814,080
41.0+	9,600,290	-	-	11,857	8,231	3,667	94,237	27,422	58,544	105,464	159,747	64,684	411,820	325,552	268,998	192,150	295,768	665,052	145,581	199,221	182,559	6,379,737

Table 4. Aboveground carbon in live trees (at least 1 inch d.b.h./d.r.c.), in short tons, on unreserved forest land, all forest types, Malheur National Forest

	Stand age 10 yr classes																					
dbh/drc class: 2" to 41"	Total	0-10 years	11-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61-70 years	71-80 years	81-90 years	91-100 years	101-110 years	111-120 years	121-130 years	131-140 years	141-150 years	151-160 years	161-170 years	171-180 years	181-190 years	191-200 years	200+ years
Total	24,687,283	90,636	223,021	355,157	270,577	246,188	537,689	932,860	2,058,468	3,948,521	3,182,617	3,710,947	1,898,268	1,375,725	710,755	783,987	1,389,415	524,474	221,547	385,365	194,398	1,627,996
1.0-2.9	259,473	857	39,252	45,319	11,617	3,785	4,469	5,960	20,744	22,757	20,292	24,698	9,081	19,123	5,051	5,346	10,421	2,220	869	2,715	487	4,412
3.0-4.9	469,074	2,681	35,342	66,660	26,515	6,195	12,801	13,236	32,199	49,711	53,128	38,484	28,007	29,873	12,259	13,192	20,306	3,885	-	3,046	1,843	19,710
5.0-6.9	586,732	4,363	15,563	32,441	23,281	9,559	25,985	32,185	58,282	88,137	61,834	59,494	44,840	36,841	16,031	11,224	26,415	4,791	4,636	9,066	2,575	19,190
7.0-8.9	1,150,844	4,363	13,129	21,890	39,006	16,234	48,895	73,593	119,816	231,637	135,478	134,714	82,570	74,016	17,507	22,371	36,584	14,500	5,274	17,159	3,889	37,564
9.0-10.9	1,735,744	6,159	12,271	11,000	44,324	18,258	51,711	107,467	188,652	331,488	227,656	237,170	106,702	106,405	45,455	35,088	77,393	30,751	7,991	16,231	3,315	69,792
11.0-12.9	2,114,815	12,954	8,363	3,885	25,795	22,705	88,164	135,318	200,690	439,007	303,588	262,526	151,033	111,078	65,629	54,818	54,037	39,792	8,485	32,674	14,839	79,434
13.0-14.9	2,574,310	11,003	14,444	14,426	31,071	15,321	103,097	124,016	268,037	498,166	369,673	390,177	163,619	112,021	62,273	94,871	90,812	65,619	5,497	22,244	10,427	107,498
15.0-16.9	2,471,279	4,320	1,543	18,878	22,998	30,040	50,967	87,767	248,619	451,583	407,682	438,686	187,727	132,151	45,353	55,818	76,692	54,344	5,015	29,772	8,988	112,338
17.0-18.9	2,314,799	-	4,034	5,752	12,831	21,642	60,102	65,964	175,423	396,161	329,231	447,730	197,822	123,170	45,978	97,103	146,298	33,357	15,307	14,864	24,377	97,655
19.0-20.9	2,025,555	7,179	5,878	5,491	8,814	6,051	2,126	37,060	153,963	358,471	293,664	399,696	188,320	92,819	52,858	60,932	137,500	20,062	27,929	25,426	16,238	125,081
21.0-22.9	1,817,598	-	26,543	22,265	-	-	25,315	43,051	129,926	254,130	166,327	317,474	169,418	107,223	82,800	57,531	103,758	54,371	37,242	13,319	11,978	188,073
23.0-24.9	1,365,779	5,160	4,310	37,593	-	14,727	14,779	42,617	123,036	224,402	121,385	219,784	91,621	63,361	17,990	53,199	123,377	36,208	16,213	35,790	26,042	94,186
25.0-26.9	1,204,395	5,250	10,892	21,243	3,735	7,148	3,368	37,768	79,555	126,524	150,774	173,454	112,815	79,043	38,809	42,843	111,979	25,189	18,780	28,426	12,679	111,982
27.0-28.9	1,127,609	9,723	13,421	20,271	10,051	14,215	7,924	45,899	57,912	119,420	113,615	174,734	63,366	67,549	48,021	39,109	86,177	32,439	12,701	30,302	20,723	140,038
29.0-30.9	862,869	-	8,069	-	-	7,203	12,811	15,891	72,777	91,123	87,246	116,679	53,186	63,598	29,532	18,902	95,156	22,678	24,376	20,539	2,636	117,403
31.0-32.9	793,787	11,144	9,969	10,156	-	14,453	6,992	13,502	25,767	65,312	88,254	66,471	88,791	62,148	24,550	30,351	81,913	37,387	11,214	24,717	14,531	106,167
33.0-34.9	489,364	5,482	-	7,192	4,020	13,546	-	6,521	9,775	51,454	69,506	57,396	39,429	36,687	28,248	27,161	27,792	19,379	3,164	13,210	4,319	65,082
35.0-36.9	456,938	-	-	-	-	14,508	5,846	24,771	20,172	56,451	65,279	52,417	37,725	13,147	6,306	4,588	36,765	22,513	16,173	26,278	3,880	50,117
37.0-38.9	309,693	-	-	-	-	10,597	5,831	8,340	28,348	21,679	33,914	43,128	29,177	18,904	25,799	22,267	19,860	-	-	5,375	5,234	31,239
39.0-40.9	212,590	-	-	4,446	-	-	6,509	6,041	13,164	13,198	36,813	20,198	17,711	17,998	22,498	10,312	13,959	4,988	683	5,031	5,399	13,642
41.0+	344,036	-	-	6,249	6,519	-	-	5,893	31,612	57,710	47,279	35,838	35,310	8,570	17,807	26,961	12,221	-	-	9,183	-	37,393

Table 5. Aboveground carbon in live trees (at least 1 inch d.b.h./d.r.c.), in short tons, on unreserved forest land, all forest types, Black Hills National Forest

	Stand age 10 yr classes																					
dbh/drc class: 2" to 41"	Total	0-10 years	11-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61-70 years	71-80 years	81-90 years	91-100 years	101-110 years	111-120 years	121-130 years	131-140 years	141-150 years	151-160 years	161-170 years		181-190 years	191-200 years	200+ years
Total	10,241,870	223,158	166,850	173,762	167,028	238,884	581,348	936,440	896,464	1,193,312	1,382,224	1,482,905	996,705	583,993	260,092	595,174	158,188	62,843		24,815	42,683	75,000
1.0-2.9	181,902	15,211	21,488	3,426	7,141	6,836	9,940	13,176	15,102	17,142	6,491	20,314	17,027	12,910	7,089	5,618	1,255	-		707	393	637
3.0-4.9	361,403	5,647	11,906	22,705	24,165	11,274	28,982	47,287	14,529	46,067	33,164	43,136	18,439	31,061	4,289	17,042	-	-		-	1,710	-
5.0-6.9	493,576	3,878	5,746	23,858	11,586	31,041	63,827	68,460	40,610	50,925	60,840	45,411	28,541	22,341	7,062	19,236	3,245	588		3,720	1,053	1,609
7.0-8.9	1,170,552	18,518	17,587	22,650	24,568	33,188	98,198	166,427	91,901	158,434	207,135	138,895	62,216	44,477	32,699	38,784	5,295	539		5,429	1,057	2,555
9.0-10.9	1,471,565	19,765	19,077	7,857	19,066	42,751	124,129	162,603	120,816	193,729	257,561	225,233	100,898	71,738	32,360	58,407	5,562	1,540		779	-	7,696
11.0-12.9	1,599,372	41,798	3,402	9,166	31,816	32,546	84,785	111,247	154,436	218,452	300,649	258,995	124,324	48,960	50,485	92,548	10,132	10,105		-	10,968	4,560
13.0-14.9	1,355,186	21,025	4,489	8,883	37,083	22,706	72,770	100,059	133,869	148,469	186,555	186,293	184,679	55,773	45,378	93,419	13,168	13,641		-	20,094	6,833
15.0-16.9	1,262,266	48,583	13,727	20,519	5,291	9,293	23,844	114,231	96,753	125,247	156,634	190,022	186,134	109,401	24,466	86,833	6,404	14,702		6,053	7,409	16,720
17.0-18.9	868,870	32,847	15,158	17,906	6,311	13,723	20,773	72,018	84,739	116,089	83,107	182,206	68,595	34,136	19,670	85,955	-	-		8,127	-	7,510
19.0-20.9	698,372	-	25,169	24,685	-	35,526	11,748	60,359	87,526	54,645	76,976	108,179	90,881	7,280	36,597	27,483	14,327	21,728		-	-	15,261
21.0-22.9	446,570	-	15,399	12,107	-	-	17,507	20,574	50,684	22,474	-	62,971	99,216	53,011	-	58,593	22,416	-		-	-	11,618
23.0-24.9	151,585	15,887	13,703	-	-	-	24,846	-	-	-	13,112	-	15,756	57,026	-	11,256	-	-		-	-	-
25.0-26.9	55,968	-	-	-	-	-	-	-	5,498	-	-	21,250	-	-	-	-	29,220	-		-	-	-
27.0-28.9	47,163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47,163	-		-	-	-
29.0-30.9	35,879	-	-	-	-	-	-	-	-	-	-	-	-	35,879	-	-	-	-		-	-	-
31.0-32.9	41,640	-	-	-	-	-	-	-	-	41,640	-	-	-	-	-	-	-	-		-	-	-

Table 6. Aboveground carbon in live trees (at least 1 inch d.b.h./d.r.c.), in short tons, on unreserved forest land, all forest types, Chequamegon-Nicolet National Forest

	Stand age 10 yr classes																				
dbh/drc class: 2" to 41"	Total	0-10 years	11-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61-70 years	71-80 years	81-90 years	91-100 years	101-110 years	111-120 years	121-130 years	131-140 years	141-150 years	151-160 years	161-170 years	171-180 years		191-200 years
Total	32,840,400	69,399	332,204	919,122	1,350,391	1,764,529	2,596,941	4,274,937	5,762,478	7,262,630	4,158,149	2,408,678	1,013,560	185,824	345,183	123,756	160,358	20,516	14,529		77,217
1.0-2.9	1,048,910	9,048	121,777	121,127	107,944	56,455	77,901	170,856	116,062	131,431	59,026	49,787	9,493	1,902	6,047	654	5,316	1,494	2,300		289
3.0-4.9	2,168,786	15,729	137,624	236,867	249,085	137,656	144,926	305,496	227,197	362,767	187,631	87,015	26,402	10,076	11,676	2,477	18,286	3,487	-		4,388
5.0-6.9	3,140,266	6,103	28,290	259,756	394,912	245,732	325,040	406,975	460,554	526,575	252,793	124,362	50,513	4,750	37,774	4,946	5,162	1,270	1,025		3,735
7.0-8.9	4,029,413	6,993	13,209	126,586	325,738	361,853	417,477	548,170	714,371	801,921	376,742	163,744	76,030	15,810	55,381	8,115	14,939	784	1,551		-
9.0-10.9	4,765,581	-	8,056	57,058	93,759	389,488	491,959	650,687	932,993	1,168,701	534,052	219,948	89,556	10,803	62,884	23,747	28,420	1,786	839		847
11.0-12.9	4,627,265	2,742	4,750	40,425	58,396	232,365	460,567	529,983	1,019,437	1,193,884	623,343	267,206	70,028	13,676	58,426	25,878	14,546	9,674	-		1,939
13.0-14.9	4,286,371	3,640	-	23,120	35,584	99,999	276,239	675,297	904,551	1,088,019	694,817	279,325	103,452	22,196	44,345	8,473	22,469	2,021	2,823		-
15.0-16.9	3,147,280	-	18,498	21,259	3,471	130,054	118,029	520,134	660,651	792,686	373,252	308,279	117,943	14,657	17,522	23,432	20,087	-	-		7,326
17.0-18.9	2,177,304	10,365	-	5,218	26,486	28,128	152,577	228,967	335,447	505,133	476,306	252,856	104,431	20,913	-	17,434	3,331	-	-		9,712
19.0-20.9	1,470,571	-	-	16,490	14,823	38,707	49,522	105,020	226,837	362,445	296,134	201,504	76,059	20,902	11,293	8,601	17,381	-	5,991		18,861
21.0-22.9	982,348	14,777	-	11,215	-	-	67,535	108,016	103,441	195,136	110,625	191,784	136,103	-	24,589	-	10,422	-	-		8,704
23.0-24.9	527,089	-	-	-	21,695	44,092	15,167	-	37,364	100,027	97,405	81,460	94,134	9,937	15,246	-	-	-	-		10,561
25.0-26.9	271,629	-	-	-	-	-	-	25,337	-	33,906	23,293	123,831	33,888	20,518	-	-	-	-	-		10,856
27.0-28.9	96,224	-	-	-	-	-	-	-	23,572	-	26,289	26,680	-	19,683	-	-	-	-	-		-
29.0-30.9	51,970	-	-	-	-	-	-	-	-	-	26,442	-	25,529	-	-	-	-	-	-		-
31.0-32.9	49,393	-	-	-	18,499	-	-	-	-	-	-	30,895	-	-	-	-	-	-	-		-

Table 7. Aboveground carbon in live trees (at least 1 inch d.b.h./d.r.c.), in short tons, on unreserved forest land, all forest types, Green & White Mountain National Forests

	Stand age 10 yr classes																
dbh/drc class: 2" to 41"	Total	0-10 years	11-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61-70 years	71-80 years	81-90 years	91-100 years	101-110 years	111-120 years	121-130 years	131-140 years		151-160 years
Total	30,510,362	19,199	25,862	153,560	345,029	1,089,940	1,731,581	3,954,712	7,224,431	8,289,032	4,806,882	1,354,487	1,137,190	182,531	151,320		44,606
1.0-2.9	942,931	1,262	17,143	26,778	22,011	89,989	89,399	130,513	189,355	207,597	123,554	20,978	14,312	2,157	2,173		5,709
3.0-4.9	1,838,334	7,526	4,017	52,010	63,989	166,338	193,193	273,660	414,891	333,498	252,694	46,912	17,436	7,783	1,905		2,481
5.0-6.9	2,081,570	2,199	979	27,386	50,983	185,421	227,255	362,793	445,697	406,477	264,974	63,516	33,620	3,545	4,709		2,015
7.0-8.9	3,396,571	2,449	2,788	20,542	44,552	250,727	326,527	625,208	773,846	720,032	417,620	107,848	79,270	8,591	13,503		3,069
9.0-10.9	3,924,959	-	934	8,367	23,407	167,099	293,923	635,753	1,011,953	911,783	567,916	147,428	126,702	10,574	10,888		8,230
11.0-12.9	4,220,439	-	-	7,391	21,403	80,434	220,387	630,975	1,103,368	1,163,876	656,866	168,757	136,007	13,882	9,053		8,041
13.0-14.9	3,716,437	5,763	-	-	19,895	59,578	136,189	400,539	979,097	1,111,537	602,930	187,758	161,782	16,508	27,661		7,198
15.0-16.9	3,307,460	-	-	-	17,594	34,106	98,595	353,733	819,258	1,008,389	626,173	174,373	139,579	8,081	19,716		7,862
17.0-18.9	2,410,619	-	-	-	9,672	21,826	60,697	165,307	548,239	808,266	477,177	192,715	88,811	37,908	-		-
19.0-20.9	2,106,948	-	-	-	15,250	20,502	56,649	170,295	428,630	714,256	378,806	82,986	182,770	18,606	38,198		-
21.0-22.9	1,178,188	-	-	11,086	17,833	-	8,584	68,471	166,140	473,375	234,137	85,234	78,240	11,573	23,515		-
23.0-24.9	508,332	-	-	-	6,018	-	12,298	21,660	162,802	160,143	101,349	8,943	35,118	-	-		-
25.0-26.9	446,062	-	-	-	-	13,920	7,884	101,770	55,353	138,532	65,638	11,172	17,547	34,246	-		-
27.0-28.9	153,528	-	-	-	-	-	-	-	58,144	35,180	12,756	21,454	25,995	-	-		-
29.0-30.9	113,328	-	-	-	-	-	-	-	25,326	62,209	-	16,716	-	9,076	-		-
31.0-32.9	79,490	-	-	-	16,259	-	-	14,036	24,902	-	24,292	-	-	-	-		-
33.0-34.9	85,167	-	-	-	16,162	-	-	-	17,429	33,880	-	17,696	-	-	-		-

Appendix 2 – Culmination of Net Primary Productivity (CNPP)

Net primary productivity, often measured in teragrams of carbon per hectare per year (tC Ha^{-1} yr^{-1}), encompasses four main components:[108]

$$NPP = \Delta B + M + L_l + L_{fr},$$

where ΔB represents rate of change in total living biomass (meaning the total mass of carbon in living stems, branches, and coarse roots), M represents rate of change in dead biomass (meaning total mass of carbon in dead standing and down wood), L_l is the rate of foliage turnover (encompassing mass of carbon in leaf turnover from living to litter), and L_{fr} is fine root turnover rate in soil (meaning the mass of carbon in roots smaller than 2 mm from living to dead).[1]

CNPP corresponds to the point at which the annual rate of a stand's carbon accumulation is at a maximum.[109] Importantly, the CNPP age is specific to the forest type, region, or forest that it represents, but it is comparable with other CNPP age values from vastly different geographies, because it compares the age at which stands reach a certain growth stage.

Statistical analyses on publicly available NPP data[110] show that the number average of CNPP age values across national forests (NFs) of the contiguous United States is 54 $\pm$ 15 years while the CNPP age value average weighted by area of national forest (see equation below) is 57 $\pm$ 15 years. The median is 50 years, which is a more accurate measure of distribution in these data because they do not follow a normal distribution. The distribution of CNPP age values is shown in the histogram in Figure 2 below. Within three standard deviations of the mean, all national forest CNPP age values are encompassed in the analysis. As shown in Figure 3, the CNPP age averages (weighted by area of NF) for each contiguous U.S. geographic region are all below 80 years of age.

$$Weighted\ CNPP\ Age\ Average =$$

$$\sum_{for\ all\ NFs} \frac{Area\ of\ NF\ (acres)}{Total\ NF\ area\ included\ in\ analysis\ (193{,}273{,}972\ acres)} * CNPP\ Age\ Average_{NF}$$

(Note: This analysis does not include Bureau of Land Management (BLM) federal forestlands. BLM administers nearly 29 million acres of federal forestlands (deciduous, evergreen, and mixed types) found in sixteen western states.[111] According to an analysis in peer review that used structurally mapped forest classifications, BLM has some 5.6 million acres of mature and old-growth forest, representing about 9% of the total mature and old-growth forests on federal lands.[112])

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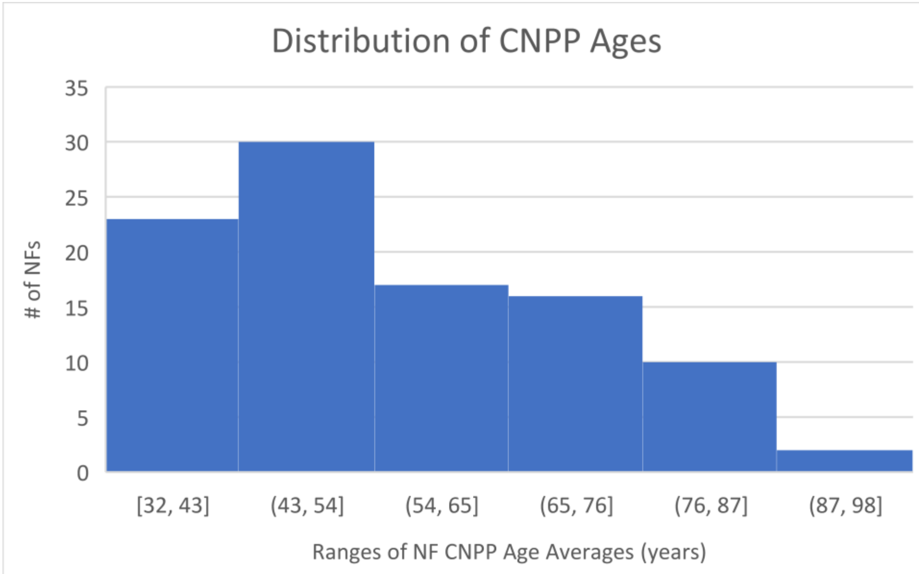

Figure 2. Histogram showing distribution of CNPP ages for forest types across the national forests of the contiguous United States reflecting original statistical analysis performed on NPP data.[113]

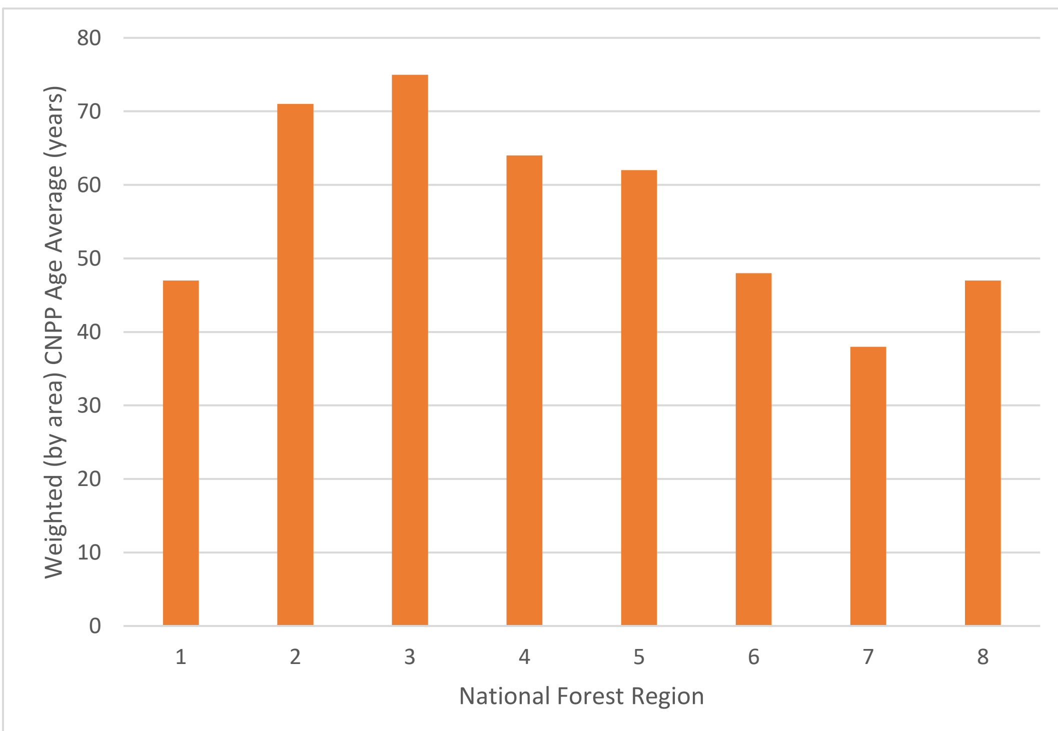

Figure 3. Weighted (by area for NF) CNPP age averages for each NF region in the contiguous United States reflecting original analysis of NPP data.[114]

[113] Birdsey, R. A. et al. "Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of U.S. national forests." General Technical Report RMRS-GTR-402. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (2019). https://doi.org/10.2737/RMRS-GTR-402.
[114] *Id.*

Table 9. Compilation of CNPP weighted by area of NF and sorted by region.

National Forest	Area (acres)	frac. of total NF area	frac. of total area NF area in contiguous U.S	CNPP Age Average	Weighted
Beaverhead Deerlodge	3,568,907	0.0158	0.0185	45	0.8309
Bitterroot	1,655,753	0.0073	0.0086	58	0.4926
Custer	1,278,749	0.0057	0.0066	50	0.3308
Flathead	2,628,720	0.0117	0.0136	45	0.6120
Gallatin	2,151,461	0.0095	0.0111	42	0.4675
Helena	1,175,125	0.0052	0.0061	61	0.3699
Idaho Panhandle	3,717,216	0.0165	0.0192	43	0.8334
Kootenai	2,145,268	0.0095	0.0111	45	0.4995
Lewis and Clark	1,999,256	0.0089	0.0103	58	0.5948
Lolo	2,639,383	0.0117	0.0137	43	0.5804
Region 1 tot.	**22,959,838**	**0.1018**	**0.1188**	**47**	
Arapaho-Roosevelt	2,073,307	0.0092	0.0107	76	0.8153
Bighorn	1,115,160	0.0049	0.0058	71	0.4080
Medicine Bow Routt	3,234,329	0.0143	0.0167	74	1.2411
Shoshone	2,466,909	0.0109	0.0128	83	1.0594
Black Hills	1,534,471	0.0068	0.0079	93	0.7344
Grand Mesa, Uncompahgre, Gunnison	3,163,130	0.0140	0.0164	57	0.9274
Pike-San Isabel	3,117,595	0.0138	0.0161	70	1.1291
White River	2,477,646	0.0110	0.0128	55	0.7051
Rio Grande	1,922,766	0.0085	0.0099	68	0.6715
San Juan	2,108,313	0.0093	0.0109	78	0.8545
Region 2 tot.	**23,213,626**	**0.1029**	**0.1201**	**71**	
Apache-Sitgreaves	2,761,386	0.0122	0.0143	81	1.1532
Gila	2,799,746	0.0124	0.0145	64	0.9271
Tonto	2,969,543	0.0132	0.0154	73	1.1267
Coronado	1,859,807	0.0082	0.0096	61	0.5894
Carson	1,591,018	0.0071	0.0082	64	0.5233
Santa Fe	1,824,776	0.0081	0.0094	64	0.6002
Cibola	2,374,882	0.0105	0.0123	66	0.8075
Coconino	2,013,804	0.0089	0.0104	78	0.8127
Lincoln	1,271,064	0.0056	0.0066	79	0.5167
Kaibab	1,601,066	0.0071	0.0083	78	0.6461
Prescott	1,407,611	0.0062	0.0073	78	0.5681
Region 3 tot.	**22,474,703**	**0.0996**	**0.1163**	**71**	
Dixie	2,022,795	0.0090	0.0105	56	0.5843
Ashley	1,402,656	0.0062	0.0073	58	0.4173
Uinta-Wasatch-Cache	2,988,077	0.0132	0.0155	53	0.8246
Caribou-Targhee	3,114,433	0.0138	0.0161	75	1.2086
Fishlake	1,539,737	0.0068	0.0080	60	0.4780
Manti-La Sal	1,338,015	0.0059	0.0069	60	0.4154
Humboldt-Toiyabe	6,863,886	0.0304	0.0355	74	2.6280

Bridger-Teton	3,439,236	0.0152	0.0178	51	0.9120
Salmon-Challis	4,283,345	0.0190	0.0222	67	1.4880
Payette	2,424,840	0.0107	0.0125	63	0.7841
Boise	2,959,305	0.0131	0.0153	63	0.9570
Sawtooth	1,894,778	0.0084	0.0098	68	0.6652
Region 4 tot.	**34,271,103**	**0.1519**	**0.1773**	**64**	
Angeles	694,814	0.0031	0.0036	39	0.1387
El Dorado	889,778	0.0039	0.0046	40	0.1841
Klamath	1,932,405	0.0086	0.0100	65	0.6499
Lassen	1,375,860	0.0061	0.0071	66	0.4678
Mendocino	1,080,071	0.0048	0.0056	41	0.2282
Plumas	1,401,423	0.0062	0.0073	40	0.2900
Sequoia	1,193,344	0.0053	0.0062	81	0.4991
Shasta-Trinity	2,814,114	0.0125	0.0146	95	1.3832
Sierra	1,417,515	0.0063	0.0073	45	0.3300
Six Rivers	1,263,760	0.0056	0.0065	40	0.2615
Tahoe	1,239,852	0.0055	0.0064	70	0.4490
Region 5 tot.	**15,302,936**	**0.0678**	**0.0792**	**62**	
Deschutes	1,853,929	0.0082	0.0096	42	0.3997
Fremont-Winema	2,810,877	0.0125	0.0145	42	0.6108
Okanogan-Wenatchee	3,454,291	0.0153	0.0179	40	0.7149
Umpqua	1,027,370	0.0046	0.0053	44	0.2326
Colville	1,029,942	0.0046	0.0053	59	0.3144
Wallowa-Whitman	2,391,979	0.0106	0.0124	70	0.8663
Malheur	1,541,723	0.0068	0.0080	77	0.6154
Umatilla	1,512,767	0.0067	0.0078	65	0.5088
Ochoco	1,152,718	0.0051	0.0060	70	0.4175
Mt. Hood	1,184,306	0.0052	0.0061	41	0.2512
Mt. Baker-Snoqualmie	2,903,408	0.0129	0.0150	36	0.5408
Rogue River-Siskiyou	1,851,875	0.0082	0.0096	39	0.3696
Siuslaw	860,619	0.0038	0.0045	35	0.1558
Olympic	698,445	0.0031	0.0036	32	0.1144
Willamette	1,790,940	0.0079	0.0093	44	0.4054
Gifford Pinchot	1,409,966	0.0063	0.0073	48	0.3465
Region 6 tot.	**27,475,155**	**0.1218**	**0.1422**	**48**	
Alabama NF	1,288,521	0.0057	0.0067	46	0.3033
Conecuh					
Talladega					
Tuskegee					
William B. Bankhead					
Chattahoochee-Oconee	1,857,781	0.0082	0.0096	38	0.3605
Florida NF	1,434,931	0.0064	0.0074	35	0.2599
Apalachicola					
Ocala					
Osceola					

Cherokee	1,212,559	0.0054	0.0063	40	0.2536
North Carolina NF	3,165,024	0.0140	0.0164	44	0.7164
Croatan					
Nantahala					
Pisgah					
Uwharrie					
Daniel Boone	2,047,092	0.0091	0.0106	43	0.4590
Land Between the Lakes	170,310	0.0008	0.0009	38	0.0330
George Washington & Jefferson	3,467,346	0.0154	0.0179	48	0.8611
Francis Marion	1,378,505	0.0061	0.0071	38	0.2675
Kisatchie	1,024,637	0.0045	0.0053	47	0.2492
Texas NF	1,915,035	0.0085	0.0099	43	0.4211
Sabine					
Sam Houston					
Angelina					
Davy Crockett					
Mississippi NF	2,317,842	0.0103	0.0120	50	0.5996
Tombigbee					
Bienville					
Delta					
De Soto					
Holly Springs					
Homochitto					
Ouachita	2,723,874	0.0121	0.0141	46	0.6518
Ozark-St. Francis	1,535,353	0.0068	0.0079	33	0.2648
Region 8 tot.	**25,538,810**	**0.1132**	**0.1321**	**38**	
Superior	3,867,142	0.0171	0.0200	46	0.9204
Chippewa	1,599,664	0.0071	0.0083	48	0.3973
Chequamegon-Nicolet	2,022,945	0.0090	0.0105	48	0.5001
Green Mountain-Finger Lakes	838,959	0.0037	0.0043	46	0.1984
White Mountain	921,649	0.0041	0.0048	46	0.2180
Allegheny	742,834	0.0033	0.0038	47	0.1794
Hoosier	644,269	0.0029	0.0033	41	0.1367
Mark Twain	3,060,162	0.0136	0.0158	47	0.7442
Monongahela	1,706,898	0.0076	0.0088	46	0.4062
Shawnee	905,045	0.0040	0.0047	47	0.2201
Wayne	833,990	0.0037	0.0043	46	0.1996
Hiawatha	1,294,645	0.0057	0.0067	49	0.3293
Huron-Manistee	2,029,890	0.0090	0.0105	48	0.4989
Ottawa	1,569,709	0.0070	0.0081	54	0.4365
Region 9 tot.	**22,037,801**	**0.0977**	**0.1140**	**47**	

Table 10. Overall statistics for CNPP data on all NFs.

Weighted CNPP Age Average =	57	years	μ - 3σ = 98	Area data from NFS website
Number CNPP Age Average (μ) =	54	years	μ + 3σ = 10	193,273,972 acres
Median =	50	years		
Std Dev (σ) =	15	years		

Appendix 3 – Culmination of Mean Annual Increment (CMAI)

A selection of available CMAI data from literature reporting on a variety of tree species in all states except Hawaii indicate that many species achieve CMAI before 80 years of age. For the data reproduced in Table 12 below, 62% of the species presented achieve CMAI by 80 years. The species presented span a range of CMAI ages between 25 and 144 years. The mean was 79 ± 26 years and the median was 80. The distribution of these selected data is shown in a histogram below in Figure 4.

These CMAI data reflect a consensus in the readily available literature rather than a comprehensive data set for all federal forests. Some species are shown multiple times in Table 11 but represent CMAI values for different sites. Each row in the table was treated as an individual CMAI measurement, equally weighted with the rest of the table. Values within a given cell in the CMAI column were averaged to yield one average CMAI value for that species/site. While these data are geographically and specifically inclusive, some regions are overrepresented (including the Pacific Northwest). As a result, statistical aggregate values cannot be viewed as comprehensively representative as (for example) the CNPP data where each federal forest is equally weighted in the analysis.

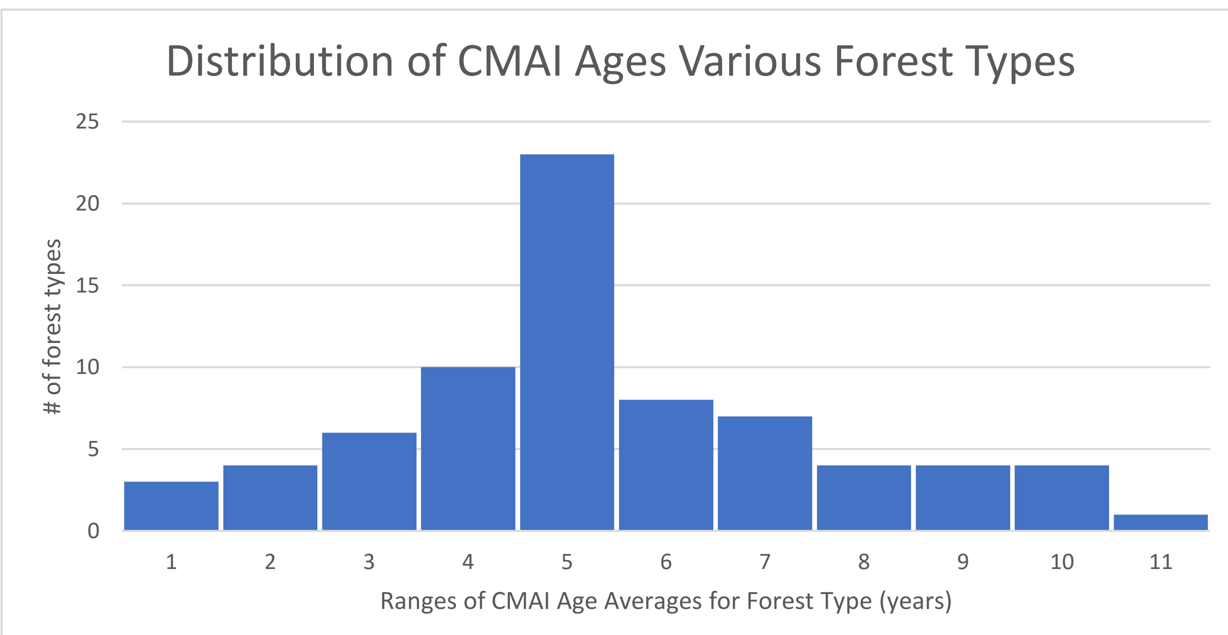

Figure 4. Distribution of selected CMAI ages for US forest types.

CMAI Table below reproduced with permission from Andy Kerr.

Table 11. Selected CMAI for Various Species at Various Sites

Species	*CMAI (Years)*	*Site*	*Source*
Douglas-fir	average 84, 80-110, 75	OR, WA, CA	1, 8, McArdle 193
Ponderosa pine	90, 30-80 (even-aged)	WA	2, Meyer 1938
Inland Douglas-fir	80–100, 72-115	WA	2, 8
Grand fir	70	WA	2
Engelmann spruce	130	WA	2
Subalpine fir	100	WA	2
Douglas-fir–ponderosa pine	90	Southwest OR	2
Tanoak	70	Southwest OR	2
Douglas-fir–white fir	60	Southwest OR	2
Western hemlock	60, 50-70	Southwest OR	2, 8
Port Orford cedar	60	Southwest OR	2
Jeffrey pine	80	Southwest OR	2
White fir–Douglas-fir	60	Southwest OR	2
Shasta red fir	80	Southwest OR	2
Western white pine	80	Southwest OR	2
Mountain hemlock	60	Southwest OR	2
Noble fir	115–130	WA, OR	3
White spruce	80–150	MN, WI, MI, NY, VT, NH, ME	3
Jack pine	50–60	MN, WI, MI, ME	3
Lodgepole pine	40–140, typically 50–80	WA, OR, ID, MT, WY, CO, UT, CA, NV	3
Yellow poplar	70	WI to LA to FL to NY	4
Quaking aspen	30, 70-110	WA, OR, CA, NV, AZ, NM, CO, UT, WY, ID, MT, ND, SD, MN, IA, WI, MI, IL, IN, OH, NY, PA, VT, NH, ME, MA, DE	4, 8
Black cottonwood	62–96	AK, WA, OR, ID, MT, CA, NV, UT, ND	4
Sitka spruce	70-100	AK, WA, OR, CA	5, 8
Eastern white pine	90–120	MN, IA, MI, WI, NY, PA, VA, WV, NC, SC, GA, TN, KY, ME, VT, NH, RI, CT	6
Balsam fir	60	MN, WI, MI, NY, VT, NH, ME	6
Oak-hickory type	70	North Central US	6
Longleaf pine	25	TX, LA, AL, MS, GA, FL, SC, NC, VA	6
Virginia pine	30+	PA, NJ, MD, DE, VA, WV, KY, OH, TN, NC, SC, GA, MS, AL	6
Western white pine	100-120	WA, OR, CA, NV, ID, MT	6, 8
Rocky Mountain Douglas-fir	120–140	WA, ID, MT, OR, UT, AZ, NM, CO, WY	6
Lodgepole pine	70–90, 100	WA, OR, CA, NV, ID, MT, WY, CO, UT	6, 8
Sitka spruce	80	OR, WA, AK	6
"True" firs (e.g. Pacific silver fir and noble fir)	130	OR, WA	6
Red pine	60–130	MN, WI, MI, NE, PA, VT, N, ME	7
Aspen (quaking or bigtooth)	40–60	MN, WI, MI, IA, IL, IN, OH, PA, NY, CT, RI, VT, NH, ME, WV, VA, KY, NC, TN	7
Eastern white pine	80–120	MN, WI, IA, IL, IN, MI, OH, NY, PA, VA, NC, GA, SC, KY, TN, VT, CT, NH, ME, RI	7
Red pine	60–120	MN, WI, MI, PA, WV, NJ, VT, NH, ME, CT, RI	7
Jack pine	40	MN, WI, MI, ME	7

Balsam fir	40–60	MN, WI, MI, NY, VT, NH, ME	7
White spruce	80–100	MN, WI, MI, NY, VT, NH, ME	7
Black spruce	60+	MN, WI, MI, NY, VT, NH, ME, CT, MA	7
Tamarack	80–130	MN, WI, MI, OH, NY, VT, NH, ME, CT	7
Black/northern pin oak	70–90	MN to TX to GA to ME (black oak); KS, OK, AR, MO, IA, IL, IN, OH, MI, TN, NC, VA, WV, MD, DE, PA, NJ, NY, CT, MA, RI (pin oak)	7
Red oak	70–100	MN to LA to SC to ME (northern); MO to TX to FL to NJ (southern)	7
White oak	80–100	MN to TX to FL to ME	7
Paper birch	50	MN, WI, MI, NY, VT, NH, ME, MA, CT, RI, PA	7
Red maple	50	MN to TX to FL to ME	7
Green ash	70	MT to TX to FL to ME	7
Black cherry	70	MN to TX to FL to ME	7
American elm	80	MN to TX to FL to ME	7
Slippery elm	80	ND to TX to SC to ME	7
Hackberry	70	ND to OK to VA to NH	7
Bitternut hickory	70	MN to TX to SC to NH	7
Shagbark hickory	80	MN to TX to VA to ME	7
White fir	70	OR, CA, NV, ID, UT, CO, NM, AZ	8
Grand fir	121	WA, OR, ID, MT, CA	8
Subalpine fir	120–150	WA, OR, CA, ID, MT, WY, UT, CO, AZ, NM	8
Shasta red fir	140	CA, OR	8
Red alder	35-42	OR	8
Western juniper	100	OR	8
Western larch	70	OR	8
Engelmann spruce	80-150	OR	8
Coast redwood	50-144	OR	8
Loblolly Pine	23-27	TX to DE	9
Oak-pine	38	ME	10
Upland Oak	80 (average site)	Both chestnut-chestnut oak-yellow poplar and oak-hickory Types	11
Sitka Spruce & Western Hemlock	71	AK, WA, & OR	12
Loblolly Pine	65	DE, MD, VA, NC, SC, TN, GA, FL, AL, MS, LA, TX, AR, OK	13
Longleaf Pine	90	VA, NC, SC, GA, FL, AL, MS, LA, TX	13
Shortleaf Pine	100	PA, NJ, OH, WV, VA, MD, VA, KY, MO, IL, TN, NC, SC, GA, FL, AL, MS, LA, TX, OK, AR	13
Slash Pine	55	SC, GA, FL, AL, MS, LA	13.
Western Hemlock-Sitka Spruce	80-140	AK, OR, WA	14
White Pine	45	WA, OR, ID, MT, NV, CA	15
Yellow Poplar	70	MI, NY, MA, CT, PA, NJ, DE, MD, WV, OH, IN, IL, KY, VA, TN, VA, NC, SC, GA,FL, AL, MS, LA, AR, MO	16.

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