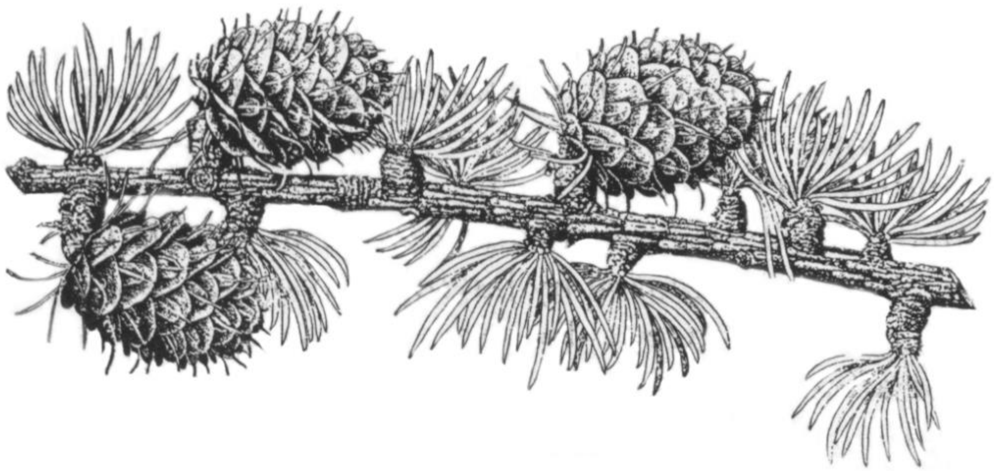

Defining the Minimum Age of a Mature Forest in Regulation Using Its Age of Ecological Maturity

by Andy Kerr [1]

The Larch Company

August 2022[2]

Dedicated to the conservation and restoration of nature, The Larch Company is a non-membership for-profit organization that represents species that cannot talk and humans not yet born. A deciduous conifer, the western larch has a contrary nature.

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[2] This is a revision and extension of an earlier paper entitled "Defining the Minimum Age of a Mature Forest in Either Legislation or Regulation," August 21, 2021.

Abstract

President Biden issued an executive order that, among other things, directs the USDA Forest Service and the USDI Bureau of Land Management to "develop policies . . . to institutionalize climate-smart management and conservation strategies that address threats to mature and old-growth forests on Federal lands."

To achieve the goals of high levels of ecosystem-based carbon storage and sequestration, biological diversity conservation, and watershed protection on federal forest lands, the conservation community seeks to protect federal mature and old-growth ("older") forests and trees by an enduring federal regulation. For such a policy, it is important to define the age at which a <u>forest stand</u> becomes "mature." To ecologists, a forest stand reaches the age of ecological maturity (AEM) upon the culmination of net primary productivity (CNPP). To forest scientists, a forest stand reaches the AEM upon the culmination of mean annual increment (CMAI).

This paper discusses CNPP and CMAI as alternative methods of determining the maturity of a forest stand and recommends using CMAI. The results of CNPP and CMAI will be approximately the same, but CMAI is recommended here because (1) it has long been used, (2) it has been widely applied, and (3) it is understood by forestry professionals and federal forestland management agencies. Like CNPP, CMAI is applicable to all forest types on all growing sites. A review of the readily available literature on CMAI found published data for seventy-five forest types. CMAI can occur as early as 25 years (lodgepole pine) and as late as 150 years (Engelmann spruce and subalpine fir).

For such an enduring and comprehensive older forest conservation regulation, it is also important to define the age at which a <u>tree</u> becomes "mature." One could use the age of sexual maturity (ASM) as the determinant of maturity for each species. Alternatively, one could apply the CMAI for a forest stand to trees on a similar growing site. This paper recommends the latter option. The AEM of a tree on a specific growing site would be the same as the CMAI for a forest stand on that site.

Recommended citation: Kerr, Andy. 2022. Defining the Minimum Age of a Mature Forest in Regulation Using Its Age of Ecological Maturity. The Larch Company, Ashland, OR and Hancock, ME.

Introduction

On Earth Day 2022, President Joe Biden issued Executive Order 14072: "Executive Order on Strengthening the Nation's Forests, Communities, and Local Economies." Among other things, the EO requires the USDA Forest Service and the USDI Bureau of Land Management (BLM) to "develop policies . . . to institutionalize climate-smart management and conservation strategies that address threats to mature and old-growth forests on Federal lands." It also requires the agencies to inventory mature and old-growth forests.[3]

Over the decades and across the broad landscape of the United States, scientists, foresters, and land managers have defined "old growth" in a plethora of ways that account for varying forest types and the intents of the definers. The Forest Service and the BLM, pursuant to the Biden executive order, have solicited public comments on how "mature" and "old-growth" should be defined.

As the Biden EO calls for identical protections to be applied to both mature and old-growth forests, having a clear-cut definition of when a forest transitions from a mature to an old-growth state is not necessary to carry out the protective provisions of the EO. A definition of old growth is necessary only in carrying out the inventory provision of the EO. However, a scientifically defensible definition of when a forest matures is necessary to carry out both the inventory and protective provisions of the EO.

In the absence of any objective criteria for what constitutes an old-growth forest or tree in the very large variety of forest types in the United States, any definition is either qualitative (descriptive) or arbitrary (stand or tree age). But there is a quantitatively objective way to determine the initial onset of maturity of any stand in any forest type: the age at which the annual growth of biomass (or a subset of biomass) of the stand culminates. Culmination can be determined based on objective measurement rather than subjective observation. Such culmination is the age of ecological maturity (AEM), also known as the age of biological maturity. It is distinct from the age of financial maturity of a timber stand, which is the age at which it is most profitable to log a stand.[4]

Once the AEM of a forest growing site is known, that age can be used to define maturity of any tree on that growing site.

When Does a Forest Stand (or Tree) Become "Mature?"

The question of when a forest stand or tree becomes mature is important to answer for purposes of a federal regulation regarding protection of mature and old-growth forests. Any single age or diameter-at-breast-height cannot be used as a defining metric for stands of trees or individual trees across the vast variety of forest types in the United States, growing as they are on sites with greatly varying rates of productivity. On better growing sites, trees tend to have a larger diameter at a given age than those growing on poorer sites.

A more precise and site-specific metric is AEM of a stand (and of trees on the same growing site). There are two fundamental ways to determine AEM: culmination of net primary

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[3] Biden, Joseph R. Jr. 2022. Executive Order on Strengthening the Nation's Forests, Communities, and Local Economies. EO 14072. The White House, Washington, DC.

[4] Jeuck, James, and Robert Bardon. June 18, 2019. Cutting at Financial Maturity: Maximizing the Economic Return of Your Woodland (web page). North Carolina State University Extension.

productivity (CNPP) and culmination of mean annual increment (CMAI). CNPP is more scientific, while CMAI is better understood by foresters and many land managers.

CNPP and CMAI are closely related. The former measures the growth of all living parts of trees and other vegetation, including roots, trunks, bark, branches, and needles (biomass) and is generally expressed in tonnes. The latter measures only the biomass that is usable wood and is generally expressed in cubic (or, very historically, board) feet.

CMAI can be readily determined using the Forest Service's Forest Inventory and Analysis (FIA), and CMAI, but not CNPP can be determined using the Forest Service's Forest Vegetation Simulator (FVS). CMAI is recommended here as the best way to determine AEM because it is more familiar to foresters and land managers that will be implementing a government policy to protect mature and older stands and trees on federal public lands.

Culmination of net primary productivity (CNPP)

Retired Forest Service scientist Richard Birdsey, now associated with the Woodwell Climate Center, in a soon-to-be-released (with others) published paper defines the culmination of net primary productivity (CNPP) as "the stand age associated with maximum NPP" (net primary productivity) and says such stand age is "the lower age boundary for defining mature forest." Birdsey notes:

> *Ecologically, CNPP occurs approximately at the age when the growing space in the ecosystem is fully covered by leaf area—i.e., tree canopy closure reaches 100%. After this age, NPP either stays constant or declines gradually, depending on tree species composition and other environmental factors such as nutrient availability.*[5]

Culmination of mean annual increment (CMAI)

In contrast to CNPP's counting of total biomass, culmination of mean annual increment (CMAI) measures only the biomass that is usable (to humans) "wood" (most of the aboveground biomass in a forest stand). CMAI is usually expressed in cubic feet of wood/acre/year, but older tables use board feet/acre/year. If expressed in cubic feet, CMAI ends up being approximately equal to CNPP.

Cubic feet is actually the only accurate way to express CMAI. Board feet is a traditional metric, but in the context of CMAI, a highly deceptive one. There are twelve board feet in a cubic foot of finished lumber, but the number of board feet in a cubic foot of unprocessed log depends upon the size of the log and other factors.[6]

In lay terms, CMAI is the age of a stand or tree of a given species on a given growing site at which the maximum annual rate of wood (and, by implication, carbon) growth peaks (culminates). While its mean annual increment (MAI) has peaked, a tree or stand can continue to sequester and store very large amounts of carbon for very long periods of time. CMAI (or CNPP)

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[5] Birdsey, Richard. July 28, 2022. Personal communication (email to Garett Rose, Natural Resources Defense Council).

[6] Verrill, Steve, Victoria L. Herian, and Henry Spelter. 2004. Estimating the Board Foot to Cubic Foot Ratio. USDA Forest Service Forest Products Laboratory Research Paper FPL-RP-616.

culminates in a forest *stand*, but *individual* trees within that stand continue to sequester and store carbon at ever-increasing rates for as long as they live.[7]

Here is how the Forest Service defines CMAI:

> *For a tree or stand of trees, the age at which the average annual increment is greatest. It coincides precisely with the age at which the current annual increment equals the mean annual increment of the stand and thereby defines the rotation of a fully stocked stand that yields the maximum volume growth.*[8]

A 1991 publication from the Forest Service's research branch notes:

> *We have also begun to realize that significant tree and forest growth occurs well beyond culmination of mean annual increment. . . . Indeed,* ***by cutting forests before or at culmination, we are cutting them at the transition from ecologically young to mature forests****; growth and biomass accumulation are very far from complete at this stage.*[9] [emphasis added and citation omitted]

The nation's premier forestry textbook notes:

> *Although [culmination of mean annual increment] was considered to represent biological maturity, forests reaching the [mature forest stage] are only just arriving at maturity from an ecological perspective. In fact, high levels of primary productivity generally continue through the [mature forest stage] and result in significant additional accumulations of wood, an important consideration in carbon sequestration.*[10]

In the 1993 scientific report that is the basis of the landmark Pacific Northwest Forest Plan, a mature forest is defined as follows:

> *Mature seral stage—The period in the life of a forest stand from culmination of mean annual increment to an old-growth stage or to 200 years. This is a time of gradually increasing stand diversity. Hiding cover, thermal cover, and some forage may be present.*[11]

Intensive management (fertilization, thinning, and such) can extend the CMAI of a stand by several decades, if not indefinitely. Such stands have far less ecological value, so it is

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[7] Stephenson, N. L., et al. January 2014. Rate of Tree Carbon Accumulation Increases Continuously with Tree Size. *Nature* 507(7490).

[8] Burns, Russell M., and Barbara H. Honkala (technical coordinators). *Silvics of North America, Volume 2: Hardwoods*. 1990. Agriculture Handbook 654. Washington, DC: USDA Forest Service.

[9] Franklin, Jerry F., and Thomas A. Spies. 1991. Composition, Function, and Structure of Old-Growth Douglas-Fir Forests. In Ruggiero, Leonard F., et al., tech. eds. *Wildlife and Vegetation of Unmanaged Douglas-Fir Forests*. Gen. Tech. Rep. PNW-285, 71–80. Portland, OR: USDA Forest Service, Pacific Northwest Research Station.

[10] Franklin, Jerry F., K. Norman Johnson, and Debora Johnson. 2018. *Ecological Forest Management*, page 61. Long Grove, IL: Waveland Press.

[11] Thomas, Jack Ward, et al. *Forest Ecosystem Management: An Ecological, Economic, and Social Assessment* (Report of the Forest Ecosystem Management Assessment Team). July 1993. Forest Service, Fish and Wildlife Service, National Marine Fisheries Service, National Park Service, Bureau of Land Management, and Environmental Protection Agency.

recommended that CMAI for climate and nature policy purposes be defined as what would naturally occur on a growing site.

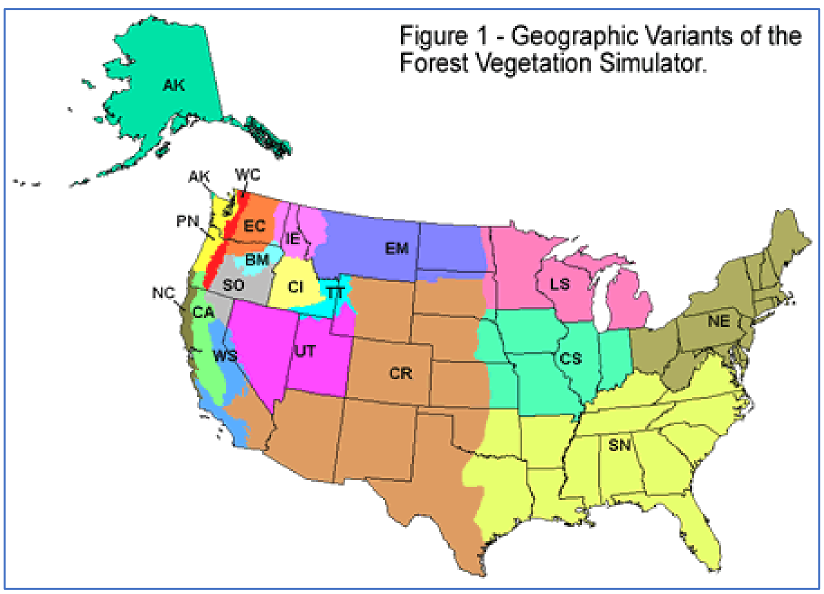
Advantages of Using CMAI

Using CMAI to define the onset of late-successional (mature and old-growth) forests is superior to alternatives of using age limits, diameter limits, or maps to define the forests and/or trees to be protected by regulation. CMAI accounts for both site- and species-specific conditions. Depending on the species and the quality of the site where the species is growing, CMAI ages differ. CMAI more accurately reflects on-the-ground differences in site and tree species to more accurately identify the point at which "mature" conditions are reached.

The Forest Service's Forest Vegetation Simulator (FVS), a forest growth simulation model, is a handy tool for determining site-specific and species-specific CMAI. (FVS does not currently encompass CNPP.)

> *It simulates forest vegetation change in response to natural succession, disturbances, and management. It recognizes all major tree species and can simulate nearly any type of management or disturbance at any time during the simulation. Outputs include tree volumes, biomass, density, canopy cover, harvest yields, fire effects, and much, much more.*[12]

FVS is a suite of software programs and includes training, background documents, and support. It is available for anyone to use. Since its initial development in 1973, FVS has evolved to include twenty-one geographic variants (Map 1). As long as stand age data is available (and it commonly is), CMAI can be calculated using FVS.[13]



Map 1. *FVS is geographically tailored, making it easy for foresters to determine CMAI for various species on various growing sites.* Source: USFS.

[12] USDA Forest Service. Forest Vegetation Simulator (FVS) (web page).
[13] Dixon, Gary. 2020 (rev.). *Essential FVS: A User's Guide to the Forest Vegetation Simulator*. USDA Forest Service.

In the field, federal foresters could determine specific trees that have reached CMAI by (1) using an increment borer to count rings; or (2) visually assessing tree age using, for example, a diameter-at-breast-height proxy.[14]

In summary, CMAI for particular forest types varies greatly by site (growing) conditions. Appendix A gives examples of CMAI for various species on various growing sites taken from various sources. While a published CMAI for every forest type is not readily available, CMAI can be determined for any species on any growing site using FVS. Appendix B compiles CMAI information on Douglas-fir. Appendix C describes a process for calculating CMAI and uses the example of typical eastside Oregon and Washington species to illustrate the process.

Age of Sexual Maturity

Another way to determine the "maturity" of a tree (but not a stand) is the age of sexual maturity (ASM) for a given species. At sexual maturity a tree can reproduce. Trees become sexually mature, depending upon species and the individual, at anywhere between 1 and 50 years of age.[15] Appendix D includes a table of the ages of sexual maturity for major native North American tree species. The average age of sexual maturity for the species in the list (n=91) is 16.9 years.

This paper recommends instead applying the CMAI for a forest stand to individual trees on a similar growing site.

Previous Uses of CMAI in National Legislation

CMAI has been used previously as a defining metric in national legislation. It was used in the National Forest Management Act of 1976 to define the age at which a stand of trees could be logged or clear-cut. It was also used as a defining metric in a discussion draft of the Pacific Northwest Forest Legacy Act proposed by Representative Peter DeFazio (D-OR-04) in 2008.

National Forest Management Act

In the National Forest Management Act of 1976, Congress directed the Forest Service to establish

> *standards to insure that, prior to harvest, stands of trees throughout the National Forest System shall generally have reached the culmination of mean annual increment of growth (calculated on the basis of cubic measurement or other methods of calculation at the discretion of the Secretary).*[16]

Congress didn't want the Forest Service clear-cutting forest stands until they had matured. The Forest Service chose to interpret the phrase "generally have reached the culmination of mean annual increment of growth" [emphasis added] to mean that a tree or stand has reached "the

[14] Van Pelt, Robert. 2007. *Identifying Mature and Old Forests in Western Washington*. Washington Department of Natural Resources.
[15] Coder, Kim D. 2019. Tree Gender and Sexual Reproduction Strategies, p. 37. Warnell School of Forestry and Natural Resources, University of Georgia, Outreach Manual WSFNR-19-21.

[16] 16 U.S.C. 1604(m)(1).

minimum age that attains 95 percent of merchantable cubic volume yield at culmination."[17] The chapter "Land Management Planning" in the *Forest Service Manual* operationalizes the definition like this:

> *7. Meet the intent of the culmination of mean annual increment (CMAI) requirement by ensuring the total yield from stands at harvest age is equal to or greater than 95 percent of the volume production corresponding to CMAI. Base CMAI on cubic measure and on the yield from regeneration harvests and any additional yields resulting from intermediate harvests.*[18]

Pacific Northwest Forest Legacy Act discussion draft

In 2008, Representative Peter DeFazio circulated a "discussion draft" of legislation he was considering introducing in the House of Representatives. The bill was never introduced. From a conservation standpoint, the discussion draft had significant upsides as well as some significant downsides. The bill would have generally protected mature and old-growth forests on Forest Service and BLM lands in the Pacific Northwest Forest Plan (the range of the northern spotted owl), as well as eastside forests of Oregon and Washington and on the Modoc National Forest in California.

In the DeFazio draft, "mature" forest was defined as "forest that has first reached the age of culmination of mean annual increment." The draft went on to say, "Such forests or trees are not yet old-growth forests or trees." The draft defined CMAI as

> *the typical age at which the greatest average annual increment is first reached for a natural, unmanaged stand of trees, which is determined by consulting published scientific references specific to tree species and productivity, as measured by Plant Association Group, site index, or both.*[19]

Recommended Regulatory Definition of "Age of Ecological Maturity"

The following definition is recommended for administrative regulation and can be applied to either natural or managed stands.

> *Culmination of Mean Annual Increment*. The "culmination of mean annual increment" means the minimum age that attains 95 percent of merchantable cubic volume yield at which the greatest average annual increment would be first reached for a natural unmanaged stand or trees on the site, which is determined by consulting published scientific references specific to tree species and productivity, the Forest Inventory and Analysis, and/or the Forest Vegetation Simulator, as measured by plant association group, site index, or both.

[17] Curtis, Robert O. 1995. Extended Rotations and Culmination Age of Coast Douglas-fir: Old Studies Speak to Current Issues. USDA Forest Service Pacific Northwest Research Station, Research Paper PNW-RP-485.
[18] USDA Forest Service. 2013. Forest Service Manual Chapter 1920—Land Management Planning.
[19] DeFazio, Peter. "Pacific Northwest Forest Legacy Act" Discussion Draft. August 6, 2008. (Copy available upon request to author of this memorandum.) Note: The bill was drafted by DeFazio's natural resources counsel Susan Jane Brown, who today serves as an attorney and director of Public Lands and Wildlife at the Western Environmental Law Center.

Conclusion

Forest scientists have found CMAI to be the best determinant of the beginning of a “mature” forest. One single age or diameter definition does not scale to the great variety of forest types and tree species across the United States. CMAI is not a single age in years, but a comparable age in stand or tree development: it’s the age of ecological maturity. CMAI is well understood by foresters and can easily be determined for specific forest types on various growing sites using the Forest Service’s own modeling software.

Appendix A
Examples of CMAI for Various Species on Various Growing Sites

Table A-1. **Selected CMAI for Various Species at Various Sites**			
Species	*CMAI (Years)*	*Site*	*Source*
Douglas-fir*	average 84, 80–110, 75	OR, WA, CA	1, 9
Ponderosa pine	90, 30–80 (even-aged)	WA	2
Inland Douglas-fir	80–100, 72–115	WA	3, 9
Grand fir	70	WA	3
Engelmann spruce	130	WA	3
Subalpine fir	100	WA	3
Douglas-fir–ponderosa pine	90	Southwest OR	3
Tanoak	70	Southwest OR	3
Douglas-fir–white fir	60	Southwest OR	3
Western hemlock	60, 50–70	Southwest OR	3, 9
Port Orford cedar	60	Southwest OR	3
Jeffrey pine	80	Southwest OR	3
White fir–Douglas-fir	60	Southwest OR	3
Shasta red fir	80	Southwest OR	3
Western white pine	80	Southwest OR	3
Mountain hemlock	60	Southwest OR	3
Noble fir	115–130	WA, OR	4
White spruce	80–150	MN, WI, MI, NY, VT, NH, ME	4
Jack pine	50–60	MN, WI, MI, ME	4
Lodgepole pine	40–140, typically 50–80	WA, OR, ID, MT, WY, CO, UT, CA, NV	4
Yellow poplar	70	WI to LA to FL to NY	5
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	5, 9
Black cottonwood	62–96	AK, WA, OR, ID, MT, CA, NV, UT, ND	5
Sitka spruce	70–100	AK, WA, OR, CA	6, 9
Eastern white pine	90–120	MN, IA, MI, WI, NY, PA, VA, WV, NC, SC, GA, TN, KY, ME, VT, NH, RI, CT	7
Balsam fir	60	MN, WI, MI, NY, VT, NH, ME	7
Oak-hickory type	70	North Central US	7
Longleaf pine	25	TX, LA, AL, MS, GA, FL, SC, NC, VA	7
Virginia pine	30+	PA, NJ, MD, DE, VA, WV, KY, OH, TN, NC, SC, GA, MS, AL	7
Western white pine	100–120	WA, OR, CA, NV, ID, MT	7, 9
Rocky Mountain Douglas-fir	120–140	WA, ID, MT, OR, UT, AZ, NM, CO, WY	7
Lodgepole pine	70–90, 100	WA, OR, CA, NV, ID, MT, WY, CO, UT	7, 9
Sitka spruce	80	OR, WA, AK	7
“True” firs (e.g. Pacific silver fir and noble fir)	130	OR, WA	7
Red pine	60–130	MN, WI, MI, NE, PA, VT, N, ME	8
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	8
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	8
Red pine	60–120	MN, WI, MI, PA, WV, NJ, VT, NH, ME, CT, RI	8
Jack pine	40	MN, WI, MI, ME	8

Table A-1. **Selected CMAI for Various Species at Various Sites (continued)**			
Species	*CMAI (Years)*	*Site*	*Source*
Balsam fir	40–60	MN, WI, MI, NY, VT, NH, ME	8
White spruce	80–100	MN, WI, MI, NY, VT, NH, ME	8
Black spruce	60+	MN, WI, MI, NY, VT, NH, ME, CT, MA	8
Tamarack	80–130	MN, WI, MI, OH, NY, VT, NH, ME, CT	8
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)	8
Red oak	70–100	MN to LA to SC to ME (northern); MO to TX to FL to NJ (southern)	8
White oak	80–100	MN to TX to FL to ME	8
Paper birch	50	MN, WI, MI, NY, VT, NH, ME, MA, CT, RI, PA	8
Red maple	50	MN to TX to FL to ME	8
Green ash	70	MT to TX to FL to ME	8
Black cherry	70	MN to TX to FL to ME	8
American elm	80	MN to TX to FL to ME	8
Slippery elm	80	ND to TX to SC to ME	8
Hackberry	70	ND to OK to VA to NH	8
Bitternut hickory	70	MN to TX to SC to NH	8
Shagbark hickory	80	MN to TX to VA to ME	8
White fir	70	OR, CA, NV, ID, UT, CO, NM, AZ	9
Grand fir	121	WA, OR, ID, MT, CA	9
Subalpine fir	120–150	WA, OR, CA, ID, MT, WY, UT, CO, AZ, NM	9
Shasta red fir	140	CA, OR	9
Red alder	35-42	OR	9
Western juniper	100	OR	9
Western larch	70	OR	9
Engelmann spruce	80–150	OR	9
Coast redwood	50–144	OR	9
Loblolly pine	23–27	TX to DE	10
Oak-pine	38	ME	11
Upland oak—chestnut, chestnut oak, yellow poplar, and oak-hickory types	80 (average site)	MN, WI, MI, NY, MA, CT, PA, NJ, DE, MD, WV, VA, NC, SC, GA, TN, MS, AR, OK, MO, IA, IL, IN	12
Sitka spruce, western hemlock	71	AK, WA, OR	13
Loblolly pine	65	DE, MD, VA, NC, SC, TN, GA, FL, AL, MS, LA, TX, AR, OK	14
Longleaf pine	90	VA, NC, SC, GA, FL, AL, MS, LA, TX	14
Shortleaf pine	100	PA, NJ, OH, WV, VA, MD, VA, KY, MO, IL, TN, NC, SC, GA, FL, AL, MS, LA, TX, OK, AR	14
Slash pine	55	SC, GA, FL, AL, MS, LA	14
Western hemlock, Sitka spruce	80-140	AK, OR, WA	15
White pine	45	WA, OR, ID, MT, NV, CA	16
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	17

* Another reference (Appendix B) says 60–130.

Sources:

1. Appendix B, McArdle, Richard E. 1930 (rev. 1948). The Yield of Douglas Fir in the Pacific Northwest. USDA Technical Bulletin 201.
2. Appendix C, Meyer , Walter H. 1938. Yield of Even-Aged Stands of Ponderosa Pine. USDA Technical Bulletin 630.
3. Appendix C.

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5. Burns, Russell M., and Barbara H. Honkala (technical coordinators). 1990. *Silvics of North America. Volume 2: Hardwoods*. Agriculture Handbook 654. Washington, DC: USDA Forest Service.
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8. Wisconsin Department of Natural Resources. Silviculture Handbook, 2431.5.
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13. Meyer, Walter H. 1937. Yield of Even-Aged Stands of Sitka Spruce and Western Hemlock. USDA Technical Bulletin 544.
14. USDA Forest Service. 1929. Volume, Yield, and Stand Table for Second-Growth Southern Pines. USDA Forest Service Miscellaneous Publication No. 50.
15. Taylor, R. F. 1934. Yield of Second-Growth Western Hemlock-Sitka Spruce Stands in Southeastern Alaska. USDA Technical Bulletin 412.
16. Watt, Richard. F. 1960. Second-Growth Western White Pine Stands: Site Index and Species Changes, Normality Percentage Trends, Mortality. USDA Technical Bulletin 1226.
17. McCarthy, Edward F. 1933. Yellow Poplar Characteristics, Growth and Management. USDA Technical Bulletin 356.

Appendix B
CMAI of Douglas-Fir

Because of the widespread distribution and commercial importance of Douglas-fir, CMAI information on it is widely available. I examine those Douglas-fir numbers in Table B-1, relying exclusively on a 1994 Forest Service research paper by Robert O. Curtis that synthesized different timber scheduling models and site conditions. In his paper, Curtis modeled ages of first reaching CMAI ("MAImax" in his paper) for natural stands using four different well-established timber models (DFSIM, SPS, ORGANON, TASS) for three Douglas-fir site classes (II, III, and IV).

To the scientists among you (save for political scientists), I apologize for what I did next. I averaged the site classes within each model, averaged the site classes between each model, averaged the averages of the models, and averaged the averages by model. The bottom-line take-home good-enough-for-government-work message is: For Douglas-fir, the average age of CMAI is 84 years; on more productive sites it can be as low as 60 years, and on less productive sites as high as 130 years—but on average it's 84 years.

***Table B-1*. Culmination of Mean Annual Increment for Douglas-Fir**

Douglas-fir Timber Model*	Site Class	Age at Which MAImax** First Reached	Lower and Upper Age Limits, 95% of MAImax	
			Lower 95%	**Upper 95%**
DFSIM	II	74	52	103
	III	74	58	108
	IV	84	70	120
	Average	*77*	*60*	*110*
SPS	II	71	52	91
	III	88	64	104
	IV	92	75	120***
	Average	*84*	*64*	*105*
ORGANON	II	90	72	130***
	III	109	85	130***
	IV	123	98	130***
	Average	*107*	*85*	*130*
TASS	II	75	60	92
	III	NA	NA	NA
	IV	60	68	120***
	Average	*68*	*64*	*106*
AVERAGE OF SITE CLASSES	*II*	*78*	*59*	*104*
	III	*90*	*69*	*114*
	IV	*90*	*78*	*123*

AVERAGE AVERAGE OF ALL MODELS		*86*	*69*	*114****
AVERAGE OF AVERAGES BY MODEL		*84*	*68*	*113****
* All "no treatment" (aka natural stands)				
** MAImax = CMAI (culmination of mean annual increment)				
*** Data was actually X+. + dropped to allow averaging.				
Data source: Curtis, Robert O. 1994. Some Simulation Estimates of Mean Annual Increment of Douglas-Fir: Results, Limitations, and Implications for Management. USDA Forest Service Pacific Northwest Research Station, Research Paper PNW-RP-471.				

Appendix C
CMAI of Typical Eastside Oregon and Washington Species

Process for Calculating Culmination of Mean Annual Increment
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April 2008

Culmination of mean annual increment (CMAI) is calculated by using yield tables derived from actual growth data or by using a growth model (Curtis 1994). Growth rates vary for a particular species depending on many factors, including site productivity, stand density, forest composition, age, management pathway, and geneotypic variability. Thus there is considerable variation in published yield tables that have been developed for individual species by different authors. The goal of this document is to lay out a process for calculating CMAI that accounts for the variability in natural systems while being easy to use, scientifically credible, and repeatable by multiple parties.

Congressman Peter DeFazio's draft Pacific Northwest Forest Legacy Act uses CMAI as a means of determining when forests are beginning to develop old forest or late-seral characteristics and thus receive legislative protection. The current language of the draft legislation states that the age of CMAI for a given stand should be based on when CMAI is *typically* and *first* reached in a *natural* stand on that *particular* growing site.

To capture the intent of this language, a process was developed to determine CMAI on specific Plant Associations (PA) in a particular federal forest administrative unit. A number of simplifying assumptions had to be made to design a process that could be applied across the entire NWFP region, while also being easily repeatable and scientifically credible. Different parties may disagree with some of these assumptions. However, this process is similar to what was done to estimate CMAI and rotation ages during the development of many national forest land management plans prior to the Northwest Forest Plan and the Eastside Screens. Likewise, it is likely very similar to what the Forest Service would propose to estimate CMAI for the purposes of the Pacific Northwest Forest Legacy Act. The process has the following steps.

1. The Forest Vegetation Simulator (FVS) should be used to model stand growth and generate yield tables from which CMAI can be calculated. This is the primary growth model used by the Forest Service. It is publicly available and likely to be maintained and updated for many years to come.

2. Within FVS, different growth model variants exist for different regions of the PNW and greater US. The appropriate variant should be used for the national forest or BLM district in question. For areas covered by multiple variants, choose the one that covers the ranger district or administrative unit in question. Default values embedded within each variant for elevation, aspect, slope, and latitude and longitude should be used. A map can be downloaded at FVS Variant Map and overview information on the different variants can be found at https://www.fs.fed.us/fvs/software/variantkey.shtml.

3. The dominant plant association (PA) of the stand or area in question should be used within FVS as the basis of defining productivity and density of natural stands. Site index may be included in the model parameters, but must be the value listed for the specific PA

and site species in the plant association guide for the national forest or BLM district in question.

4. Yield tables should be based on even-aged stands that receive no intermediate stand entries (precommercial or commercial thinning). Conceptually, CMAI is based on even-aged stands and is problematic to calculate in uneven-aged stands and for specific cohorts. Natural stands in some plant associations are often uneven-aged. However, even in these PAs, natural even-aged stands, or large even-aged patches, also exist. Even if most natural stands for a specific PA are uneven-aged, the even-aged CMAI for that PA is still a good indicator of when mature and old forest characteristics begin to occur. Thus rather than attempting to calculate CMAI for uneven-aged stands, the process sticks with even-aged stands.

5. To generate a yield table, a stand in a specific PA should be planted within FVS and grown out to an age that is very likely beyond the CMAI. Species composition of planted trees should be based on the percent cover of overstory trees for a specific PA listed in the plant association guide for the national forest in question. For any federal administrative unit that does not have its own plant association guide, a guide from a nearby and ecologically similar national forest should be used. Species with 5% or less mean relative cover should not be included to simplify modeling.

6. Initial stand density for the year of origin used to generate yield tables should be based on the formula shown below. The sum of overstory cover for all species, derived for specific PA in the respective plant association guide, is used as an approximate measure of the stocking level of natural stands in each PA. Stands with less overstory cover generally have less carrying capacity, as measured by maximum stand density index (SDI). The maximum SDI for each PA used by FVS is shown in the appendix tables of the FVS variant overview files, which can be accessed at https://www.fs.fed.us/fvs/documents/guides.shtml. The formula below makes the assumption that PA's with more carrying capacity generally have higher stocking under natural stand development, and thus start out at a higher density. Natural regeneration is inherently difficult to predict, and stands start out at a wide range of initial densities depending on a large number of factors. While natural regeneration extensions exist for some FVS variants and could be used, they do not yet exist for all FVS variants. Plus, many natural stands go through long periods of stand establishment and/or shrub competition, which is difficult to account for in this FVS modeling process.

   Also, natural stands in some drier PAs typically develop with multiple partial disturbances such as low to moderate intensity fires. These disturbances lower stand density and thus typically prolong CMAI. Instead of trying to estimate the number and intensity of these disturbances, this process assigns lower initial stocking to account for this. These dry forest PAs have lower overstory cover and thus receive lower initial stocking under the formula below.

7. The formula below is meant to provide a simple, common initial density and avoid multiple methodologies of determining initial stand density. The formula is based on low estimates of initial stocking that generally occur under natural regeneration. As lower initial stocking results in a later CMAI, using higher initial stocking numbers will result in a lower CMAI. If agency staff or others argue that higher initial stocking is closer to actual conditions, the CMAI will be lower.

0–50% total overstory cover	100 trees per acre (TPA)
51–65% total overstory cover	200 TPA
66–80% total overstory cover	300 TPA
81+% total overstory cover	400 TPA

8. Total stem cubic volume should be used as the basis for determining the age when CMAI is reached.

Due to many factors the same plant association may have different productivity levels and carrying capacity and thus different CMAI in different regions and federal forest administrative units. Thus CMAI should not be calculated for a PA across the entire Pacific Northwest but instead should be calculated for specific federal administrative units. To demonstrate how the process works, it was used to calculate CMAI for a range of PAs on the Wenatchee National Forest, from a very dry ponderosa PA to an upper elevation sub-alpine fir PA (Table C-1). In addition, the process was used to calculate CMAI for a range of PAs on the Rogue-Siskiyou NF (Table C-2) using the Klamath Mountains (NC) variant of FVS.

To further illustrate how the calculation of CMAI was done, the step-by-step process is explained below for one PA on the Wenatchee NF:

1. The Eastside Cascades variant of the Forest Vegetation Simulator (FVS) was used as the growth model.

2. A range of plant associations was chosen to show a range of forest types and tree species. The location code corresponding to the Wenatchee National Forest was entered. No variables for elevation, age, aspect, or site index were entered and thus the model used the default values as described in the East Cascade Variant Overview (accessed at https://www.fs.fed.us/fvs/documents/guides.shtml).

3. For each plant association, a stand was planted that contained the proportion of overstory tree species that is listed in Appendix B of the Field Guide for Forested Plant Associations of the Wenatchee NF, http://www.fs.fed.us/pnw/pubs/gtr359.pdf. For example, Appendix B (page 290) lists PSME/PUTR (Douglas-fir/bitterbrush) PA as having 16% mean relative cover of Ponderosa Pine and 10% for Douglas-fir. Given a starting density of 300 TPA, this equates proportionally to 185 TPA of Ponderosa Pine and 115 of Douglas-fir. Any other species with 5% or less mean relative cover would have been ignored.

4. The stands were grown out 150 years at 10-year intervals and a yield table was generated for total stem cubic volume. From this yield table, mean annual increment was calculated at 10 year points. The CMAI was found to be at 70 years for this PA.

References

Curtis, Robert O. 1994. Some Simulation Estimates of Mean Annual Increment of Douglas-Fir: Results, Limitations, and Implications for Management. USDA Forest Service Pacific Northwest Research Station, Research Paper PNW-RP-471.

Table C-1. CMAI, Total Overstory Cover, and Species Composition for a Range of Plant Associations on the Wenatchee National Forest									
		Total OS		Species Composition (%)					
Plant Association Group	CMAI Age	Cover (%)	Initial TPA	PP	DF	LP	GF	ES	AF
PIPO/CARU-AGSP Ponderosa pine/pinegrass-wheat grass	90	35	100	94	6				
PSME/PUTR Douglas-fir/bitterbrush	90	26	100	62	38				
PSME/CAGE Douglas-fir/elk sedge	100	57	200	21	79				
PSME/SYAL Douglas-fir/common snowberry	80	84	400	25	63	12			
ABGR/SPEBL/PTAQ Grand fir/shiny-LFspirea/bracken fern	70	72	300	21	50	17	13		
PIEN/EQAR Engelmann spruce/horsetail	130	88	400		28			51	20
ABLA2/PAMY-WEN Subalpine fir/pachistima	100	76	300		34	32		16	18
PP: Ponderosa Pine; DF: Douglas-fir; LP: Lodgepole Pine; GF: Grand-fir; ES: Engelmann Spruce; AF: Sub-alpine-fir									

Table C-2. CMAI, Total Overstory Cover, and Species Composition for a Range of Plant Associations on the Rogue-Siskiyou National Forest									
		Total OS		Species Composition (%)					
Plant Association Group	CMAI Age	Cover (%)	Initial TPA	PP	DF	IC	WF	RF	OS
PIPO-PSME Douglas-fir-ponderosa pine	90	47	100	34	36	30			
LIDE3/VAOV2-GASH Tanoak/evergreen huckleberry-salal	70	51	200		100				
PSME-ABCO Douglas-fir-white fir	60	63	200		81		19		
TSHE/GASH Western hemlock/salal	60	68	300		74				26
CHLA/GASH Port-Orford-cedar/salal	60	77	300		68				32
PIJE-QUVA Jeffrey pine-huckleberry oak	80	31	100			16			84
ABCO-PSME White fir-Douglas-fir	60	79	300		63		37		
AEMAS/POPU Shasta red fir/skunkleaf polemonium	80	64	200				19	81	
PIMO/XETE Western white pine/beargrass	80	50	100						100
TSME/POPU Mountain hemlock/skunkleaf polemonium	60	66	300					32	68
PP: Ponderosa Pine; DF: Douglas-fir; IC: Incense Cedar; WF: White-fir; RF: Red-fir; OS: Other conifers									

Appendix D
Age of Sexual Maturity for Major North American Native Tree Species

Table D-1. Age of Sexual Maturity for Major North American Native Tree Species					
Common Name	*Year*	*Common Name*	*Year*	*Common Name*	*Year*
American basswood	15	Lodgepole pine	6	Shellbark hickory	40
American beech	40	Longleaf pine	25	Shumard oak	25
American elm	15	Mockernut hickory	25	Sitka spruce	20
Atlantic white-cedar	8	Monterey pine	7	Slash pine	8
Balsam poplar	9	Northern red oak	25	Slippery elm	15
Bigtooth aspen	12	Northern white-cedar	22	Southern magnolia	10
Bitternut hickory	30	Nutmeg hickory	30	Southern red oak	25
Black cherry	5	Nuttal oak	5	Sugarberry	15
Black locust	6	Osage orange	10	Swamp chestnut oak	20
Black oak	20	Overcup oak	25	Swamp cottonwood	10
Black walnut	8	*Pacific silver fir*	*30*	Swamp white oak	20
Black willow	10	Pecan hickory	15	Sweetgum	22
Blue spruce	20	Pignut hickory	30	Sycamore	6
Bur oak	35	Pin cherry	2	Table Mountain pine	5
Butternut	20	Pin oak	20	Tamarack	10
California black oak	30	Pinyon	35	Virginia juniper	10
Chestnut oak	20	Pitch pine	7	Virginia pine	5
Coast redwood	7	Pond pine	6	Water hickory	20
Common persimmon	10	Port Orford-cedar	9	Water oak	20
Douglas-fir	7	Post oak	25	Water tupelo	6
Eastern cottonwood	10	Pumpkin ash	10	Western hemlock	25
Eastern hemlock	22	Quaking aspen	12	Western larch	25
Eastern hophornbeam	25	Red mulberry	10	Western redcedar	18
Eastern redbud	5	Red pine	15	Western white pine	20
Eastern white pine	7	Red spruce	35	White ash	20
Florida dogwood	6	*Rocky Mountain bristlecone pine*	*20*	White oak	20
Giant sequoia	20	Rock elm	20	White spruce	30
Jack pine	6	Sand pine	5	Willow oak	20
Laurel oak	15	Sassafras	10	Yellow poplar	15
Live oak	25	Scarlet oak	20		
Loblolly pine	7	Shagbark hickory	40		

Note: “Major” trees are those featured in *Silvics of North America.* Ages of sexual maturity (ASM) are from “Tree Gender and Sexual Reproduction Strategies,” except for the two in italics, which are from “Juvenility, Maturation, and Rejuvenation in Woody Plants.”

Sources:

Burns, Russell M., and Barbara H. Honkala (technical coordinators). 1990. *Silvics of North America, Volume 1: Conifers*. Agriculture Handbook 654. Washington, DC: USDA Forest Service.

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Coder, Kim D. 2019. Tree Gender and Sexual Reproduction Strategies. Warnell School of Forestry and Natural Resources, University of Georgia, Outreach Manual WSFNR-19-21.

Hackett, Wesley P. 1985. Juvenility, Maturation, and Rejuvenation in Woody Plants. Chapter 3 in *Horticultural Reviews*, Volume 7.