Site Index Equations and Mean Annual Increment Equations for Pacific Northwest Research Station Forest Inventory and Analysis Inventories, 1985-2001

Erica J. Hanson, David L. Azuma, and Bruce A. Hiserote

Abstract

Site index equations and mean annual increment equations used by the Forest Inventory and Analysis Program at the Portland Forestry Sciences Laboratory, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture. The equations are for 24 tree species in California, Oregon, and Washington.

Keywords: Site index equations, mean annual increment equations.

Introduction

The Forest Inventory and Analysis Program (FIA), a program within the Pacific Northwest Research Station (PNW), USDA Forest Service, is mandated to inventory, assess, and report on several forest characteristics, traditionally timberland area and volume, on all forested lands in the United States (public and private). This document presents the site index equations and mean annual increment equations used for tree species within the PNW-FIA forest inventory area of California, Oregon, and Washington in order to document the past and present inventories.

The PNW-FIA used equations from many documents to obtain a site index value and mean annual increment for every forested inventory plot. This set of equations has been used since the 1980s inventories; equations used before then are no longer used. Specifically, this set was used for periodic inventories in Oregon (1985, 1995, and 1998), Washington (1988, 1990, and 2000), and California (1991).

Site Index

What Is Site Index?

Site index is a measure of a forest's potential productivity. Site index is usually defined as the height of the dominant or codominant trees at a specified age in a stand. It is calculated in an equation that uses the tree's height and age. Site index equations differ by tree species and region.

1 Erica J. Hanson is a forestry technician, David L. Azuma is a research forester, and Bruce A. Hiserote is a forester, Forestry Sciences Laboratory, P.O. Box 3890, Portland, OR 97208-3890.
Forest mensurationists develop site index equations through fieldwork and analysis of data. First, they establish research plots in stands of a particular tree species covering a range of site conditions. They select representative dominant or codominant trees and measure their heights, ages, and diameters. Site index curves are constructed by using the tree heights at a base age, typically 50 or 100 years in the West, usually for trees in even-aged stands. An equation is derived from the curves to estimate the site index when an individual tree's age is not the same as the base age. Site index equations are developed either by following a stand through time (King 1966) or comparing several stands of different ages at a single point in time (McArdle and others 1961).

Site index can help predict timber productivity, wood volume, and potential rate of growth of a forest. Forest managers use the site index to evaluate the quality of their land. For PNW-FIA, the site index was used primarily as input to the mean annual increment (MAI) equations, which in turn were used to develop the site classes: six classes of volume growth per acre at culmination in fully stocked natural stands. The area was reported by site class in a table, “Area of timberland, by cubic-foot site class and owner class,” in resource bulletins for each inventory (see Waddell and Bassett 1997 for an example). Another use was to separate “timberland” plots from “other forest-low productivity” plots (formerly called “noncommercial unproductive forest land”), based on whether the site can produce 20 cubic feet • acre⁻¹ • year⁻¹. The PNW-FIA also used the site index to calculate annual squared diameter growth if the previous diameter was unavailable (to obtain annual volume growth), and to calculate projected and estimated tree heights (to obtain missing growth components). Other researchers used the PNW-FIA site index of plots for growth predictions.

Some equations may have limitations owing to the method used to construct the site index curve or equation. Discussion of the different methods, and a summary of the modeling approach and number of trees sampled in most of these cited sources, can be found in Hann (1995).

**Mixed conifer**—Large areas of California forests had no main softwood tree species as the forest type, but instead were classified as mixed conifer. The PNW-FIA defined a mixed-conifer site as one within a certain region and capable of greater than 70 percent conifer stocking, and that had certain tree species predominating. In general, these plots had some mix of ponderosa pine, Jeffrey pine, sugar pine, Douglas-fir, red fir, Shasta red fir, incense cedar, and white fir (see app. 1 “Names of Trees” for scientific names). Mixed-conifer types grow on the east-facing slopes of the Coast Range, on the west-facing and higher elevation east-facing slopes of the Cascade Range and Sierra Nevada, and can extend into southern California.

**Black cottonwood**—No site index equation was available for black cottonwood, so a site index value for use in MAI equations and stocking values was developed in-house by using data from plots in cottonwood stands.
McArdle’s and King’s site index equations—In 1930, Richard E. McArdle and Walter H. Meyer published the first set of site index curves for Douglas-fir in the Pacific Northwest (McArdle and others 1961). In 1966, James E. King published a new set to account for changes since then: shorter rotations, younger trees, and improved methods of constructing curves (King 1966). In the coastal Douglas-fir region, PNW-FIA preferred the King site index equation for Douglas-fir. However, King’s method required at least 25 mainstand trees within an area not larger than a 130-foot-diameter circle. If that amount of stocking was not present on or near the plot, the field crew used the McArdle site index equation and selection method.

- McArdle selection method for PNW-FIA: Select three dominant, suppression-free trees that were greater than 50 years old.

- King selection method for PNW-FIA: If the stand was over 30 years old, locate an area no greater than a 130-foot-diameter circle that contains 25 mainstand trees, not younger or shorter than the general canopy. From the 25 trees, select the 5 with the greatest diameter at breast height. If the stand is aged 15 to 30 years old, select the 10 with the largest diameter out of 50 trees. King’s is only used in stands less than 130 years old and below 3,000 feet in elevation.

Dunning’s site index conversion—The PNW-FIA used Dunning’s site index for mixed-conifer plots in California. Other site index values used by PNW-FIA needed to be converted to Dunning’s site index so they could be used as a variable in the plant stockability factor equations (see MAI section below). The following conversion equations were used if the site index taken for the plot was not Dunning’s:

<table>
<thead>
<tr>
<th>Site index equations</th>
<th>Conversion equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (King) and 5 (Wiley)</td>
<td>( DSI = 3.07 \times (SI^{0.9}) )</td>
</tr>
<tr>
<td>4 (Herman) and 8 (Barrett)</td>
<td>( DSI = 1.54 \times (SI^{0.98}) )</td>
</tr>
<tr>
<td>7 (Krumland), 16 (M.C.), and 17 (Schumacher)</td>
<td>( DSI = 4.74 \times (SI^{0.82}) )</td>
</tr>
<tr>
<td>9 (Dahms)</td>
<td>( DSI = 1.75 \times (SI^{0.96}) )</td>
</tr>
</tbody>
</table>

where: \( DSI \) = Dunning’s site index, and \( SI \) = site index in feet.

Equations from other regions—Some equations were developed outside of the PNW-FIA region, such as site index equation no. 6 for Engelmann spruce in the northern and central Rocky Mountains (Brickell 1966). Because no similar site equation existed for Oregon or Washington, it was used for Engelmann spruce in this region.

Site trees were selected and measured on every forest land plot (10 percent or more stocked by trees), and when possible on “western woodland types” forest (5 percent or more stocked by juniper or other nontimber species). Since 1991, PNW-FIA mapped and collected plot data based on the “condition class” encountered on the plots. Although this sometimes resulted in more than one forested condition class on a single plot, site trees were collected across the plot, and only one site index was assigned to the plot. It was not believed that site varied over the area of the plot.
<table>
<thead>
<tr>
<th>Site index equation group number</th>
<th>Species</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Douglas-fir</td>
<td>WOR except Jackson and Josephine Counties</td>
</tr>
<tr>
<td>1</td>
<td>Douglas-fir</td>
<td>WWA except in silver fir zone</td>
</tr>
<tr>
<td>1</td>
<td>Douglas-fir</td>
<td>CA except in mixed conifer</td>
</tr>
<tr>
<td>1</td>
<td>Grand fir</td>
<td>WOR except Jackson and Josephine Counties</td>
</tr>
<tr>
<td>1</td>
<td>Grand fir</td>
<td>WW A</td>
</tr>
<tr>
<td>1</td>
<td>Western white pine</td>
<td>WWA</td>
</tr>
<tr>
<td>1</td>
<td>White fir</td>
<td>WOR except Jackson and Josephine Counties</td>
</tr>
<tr>
<td>2</td>
<td>Douglas-fir</td>
<td>Jackson and Josephine Counties in WOR</td>
</tr>
<tr>
<td>3</td>
<td>Grand fir</td>
<td>Jackson and Josephine Counties in WOR</td>
</tr>
<tr>
<td>3</td>
<td>White fir</td>
<td>Jackson and Josephine Counties in WOR</td>
</tr>
<tr>
<td>4</td>
<td>White fir</td>
<td>CA</td>
</tr>
<tr>
<td>4</td>
<td>Noble fir</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>4</td>
<td>Shasta red fir</td>
<td>All WOR, EOR</td>
</tr>
<tr>
<td>4</td>
<td>Pacific silver fir</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>4</td>
<td>Subalpine fir</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>4</td>
<td>Mountain hemlock</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>5</td>
<td>Western hemlock</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>5</td>
<td>Sitka spruce</td>
<td>All WOR, WW A, CA</td>
</tr>
<tr>
<td>6</td>
<td>Engelmann spruce</td>
<td>All WOR, EOR, EWA, WW A</td>
</tr>
<tr>
<td>7</td>
<td>Redwood</td>
<td>All WOR, CA</td>
</tr>
<tr>
<td>8</td>
<td>Ponderosa pine</td>
<td>All WOR, EOR, EWA, WW A</td>
</tr>
<tr>
<td>8</td>
<td>Jeffrey pine</td>
<td>All WOR, EOR, EWA, CA</td>
</tr>
<tr>
<td>8</td>
<td>Coulter pine</td>
<td>CA</td>
</tr>
<tr>
<td>8</td>
<td>Bishop pine</td>
<td>CA</td>
</tr>
<tr>
<td>9</td>
<td>Lodgepole pine</td>
<td>All WOR, EOR, EWA, WW A</td>
</tr>
<tr>
<td>9</td>
<td>Western white pine</td>
<td>All WOR, EOR</td>
</tr>
<tr>
<td>10</td>
<td>Western red cedar</td>
<td>All WOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>11</td>
<td>Black cottonwood</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>11</td>
<td>Fremont poplar</td>
<td>All WOR, EOR, EWA, WW A, CA</td>
</tr>
<tr>
<td>12</td>
<td>Western larch</td>
<td>All WOR, EOR</td>
</tr>
<tr>
<td>13</td>
<td>Red alder</td>
<td>All WOR, EOR, EWA, WW A</td>
</tr>
<tr>
<td>13</td>
<td>Other hardwoods</td>
<td>All WOR, EOR, EWA, WW A</td>
</tr>
<tr>
<td>14</td>
<td>Douglas-fir</td>
<td>WWA in silver fir zone</td>
</tr>
<tr>
<td>14</td>
<td>Douglas-fir</td>
<td>EOR and EWA</td>
</tr>
<tr>
<td>14</td>
<td>Grand fir</td>
<td>EOR and EWA</td>
</tr>
<tr>
<td>14</td>
<td>White fir</td>
<td>EOR and EWA</td>
</tr>
<tr>
<td>15</td>
<td>Western larch</td>
<td>WW A and EWA</td>
</tr>
<tr>
<td>15</td>
<td>Western white pine</td>
<td>EWA</td>
</tr>
<tr>
<td>16</td>
<td>Mixed conifer</td>
<td>CA</td>
</tr>
<tr>
<td>17</td>
<td>Red fir, Shasta red fir</td>
<td>CA</td>
</tr>
</tbody>
</table>

WOR = western Oregon.
WWA = western Washington.
EOR = eastern Oregon.
EWA = eastern Washington.
On new plots, as of 2001, data from at least 3, and sometimes 5 or 10, site trees were collected, depending on the size of the trees and the selection method used. On western woodland types, data from at least one were collected (if the species was juniper). When a crew revisited a plot, they measured one new site tree, and sometimes remeasured the previous site trees if they were in the lower age range, and a new site index was calculated for the plot.

A good site tree was a tree that was classified as a dominant within the stand (unless King’s was used, which took the five with largest diameter), had never been suppressed, and had a normally formed top. The species should represent the forest within the sampled condition, with the preferred site species in western Oregon, western Washington, and northwestern California being Douglas-fir. Trees aged 50 years and older (King’s method: 30 years) were desirable, but it was not always possible to obtain them, and younger trees could be measured. In California, the species and site equation also were determined by whether the plot was in the mixed-conifer type, which depended on the county, elevation, and percentage of conifer stocking of the stand.

Table 1 shows which site index equations were used for species and area.

For all equations:

\[
\begin{align*}
H & = \text{height in feet}, \\
\text{EXP} & = \text{natural exponent, and} \\
\text{Ln} & = \text{natural log.}
\end{align*}
\]


a. If King’s selection method was used to select site trees (only Douglas-fir and grand fir could be used), use:

\[
SI_k = \frac{2500}{A^2} \left\{ \left( \frac{H - 4.5}{0.109757 + 0.00792236A + 0.000197693A^2} \right) - 0.954038 - 0.0558178A + 0.000733819A^2 \right\} + 4.5,
\]

where

\[
\begin{align*}
SI_k & = \text{King’s site index in feet for breast height age 50 years, and} \\
A & = \text{breast-height age.}
\end{align*}
\]

---

b. For Douglas-fir and grand fir, if King’s selection method was not used and trees were < 40 years old, use the following to obtain McArdle’s site index (equation derived from McArdle and others 1961). This equation also was used for western white pine in western Washington when age < 40 years.

\[ S_I_M = EXP \left\{ 3.3 - [0.8 \ln (A)] \right\} (0.96H - 2.66) \]

where

\[ S_I_M = \text{McArdle's site index in feet for breast-height age 50 years, and} \]
\[ A = \text{breast-height age.} \]

c. For Douglas-fir and grand fir, if King’s selection method was not used and trees were ≥ 40 years old, use the following to obtain McArdle’s site index (equation derived from McArdle and others 1961). This equation also was used for western white pine in western Washington when age ≥ 40 years.

\[ S_I_M = EXP \left\{ 2.1 - [0.47 \ln (A)] \right\} (0.96H - 2.66) \]

where

\[ S_I_M = \text{McArdle's site index in feet for breast-height age 50 years, and} \]
\[ A = \text{breast-height age,} \]

McArdle’s site index was converted to King’s site index by the equation from King (1966):

\[ S_I_K = 21.5 - 0.18127(A + 8) + 0.72114 S_I_M \]

where

\[ A = \text{breast-height age,} \]
\[ S_I_K = \text{King's site index, and} \]
\[ S_I_M = \text{McArdle's site index.} \]


\[ S_I = 84.47 - AB + B(H - 4.5) \]

where

\[ A = EXP \left\{ -0.37496 + 1.36164 \ln (a) - 0.00243434 [\ln (a)]^2 \right\} \]
\[ B = 0.52032 - 0.0013194 a + \frac{27.2823}{a} \]
\[ S_I = \text{site index in feet for breast-height age 50 years, and} \]
\[ a = \text{breast-height age.} \]
3. White fir and grand fir in Jackson and Josephine Counties, Oregon (Cochran 1979c).

\[
SI = (H - 4.5) \exp(X1) - \exp(X1 + X2) + 89.43 ,
\]

where

\[
X1 = 3.8886 - 1.8017 \ln(A) + 0.2105 [\ln(A)]^2 \\
-0.0000002885 [\ln(A)]^5 + 0.0000000000000001187 [\ln(A)]^{24},
\]

\[
X2 = -0.30935 + 1.2383 \ln(A) + 0.001762 [\ln(A)]^4 \\
-0.0000054 [\ln(A)]^7 + 0.0000002046 [\ln(A)]^{11} - 0.00000000000404 [\ln(A)]^{18},
\]

\[
SI = \text{site index in feet for breast-height age 50 years, and} \\
A = \text{breast-height age},
\]

4. Noble fir, Shasta red fir in Oregon, subalpine fir, white fir, Pacific silver fir, and mountain hemlock (Herman and others 1978).

Note: For California, when white fir was found in mixed-conifer stands, the mixed-conifer site index equation was used.

a. For site trees 100 years or less:

\[
SI = [4.5 + 0.2145 (100 - A) + 0.0089 (100 - A)^2] \\
+ \left[ 1.0 + 0.00386 (100 - A) + 1.2518 (100 - A)^5 \right] \frac{10^{10}}{(H - 4.5)} ,
\]

where

\[
SI = \text{site index in feet for breast-height age 100 years, and} \\
A = \text{breast-height age}.
\]

b. For site trees > 100 years:

\[
SI = \left[ -62.755 + 672.55 \left( \frac{1}{A} \right)^{0.5} \right] + \left[ 0.9484 + 516.49 \left( \frac{1}{A} \right)^2 \right] (H - 4.5) \\
+ \left[ -0.00144 + 0.1442 \left( \frac{1}{A} \right) \right] (H - 4.5)^2 ,
\]

where

\[
SI = \text{site index in feet for breast-height age of 100 years, and} \\
A = \text{breast-height age}.
\]

a. For trees \( \leq 120 \) years in age:

\[
SI = 2500 \left( \frac{(H - 4.5)(0.1394 + 0.0137A + 0.00007A^2)}{[A^2 - (H - 4.5)(-1.7307 - 0.0616A + 0.00192A^2)]} \right) + 4.5 ,
\]

where

- \( SI \) = site index in feet for breast-height age 50 years, and
- \( A \) = breast-height age.

b. For trees > 120 years old, we used the 50-year index equation derived from Barnes (1962):

\[
SI = 4.5 + 22.6 \exp \left[ (0.014482 - 0.001162 \ln A) (H - 4.5) \right] ,
\]

where

- \( SI \) = site index in feet for breast-height age 50 years, and
- \( A \) = breast-height age.


\[
SI = H + 10.717283 \left[ \ln (A) - \ln (50) \right] \\
+ 0.0046314777 \left( \frac{10^{10}}{A^5} - 32 \right) \\
+ 0.74471147H \left( \frac{10^4}{A^2} - 4 \right) \\
- 26413.763H (A^{-2.5} - 50^{-2.5}) \\
- 0.042819823H [\ln (A) - \ln (50)]^2 \\
- 0.0047812062H^2 \left( \frac{10^4}{A^2} - 4 \right) \\
+ 0.000004925436H^2 \left( \frac{10^{10}}{A^5} - 32 \right) \\
+ 0.00000021975906H^3 \left( \frac{10^{10}}{A^5} - 32 \right) \\
+ 5.1675949H^3 (A^{-2.75} - 50^{-2.75}) \\
- 0.00000014349139H^4 A + 2 \\
- 9.481014H^4 (A^{-4.5} - 50^{-4.5}) ,
\]

where

- \( SI \) = site index in feet for total age 50 years, and
- \( A \) = total age.
Table 2—Average total height of dominant redwood sprouts by breast-height age and site index

<table>
<thead>
<tr>
<th>Breast height age</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>19</td>
<td>22</td>
<td>24</td>
<td>26</td>
<td>28</td>
<td>30</td>
<td>32</td>
<td>34</td>
<td>36</td>
<td>39</td>
<td>42</td>
</tr>
<tr>
<td>15</td>
<td>22</td>
<td>26</td>
<td>29</td>
<td>33</td>
<td>37</td>
<td>40</td>
<td>44</td>
<td>48</td>
<td>52</td>
<td>56</td>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>20</td>
<td>27</td>
<td>32</td>
<td>37</td>
<td>41</td>
<td>46</td>
<td>51</td>
<td>56</td>
<td>61</td>
<td>67</td>
<td>72</td>
<td>78</td>
<td>83</td>
</tr>
<tr>
<td>25</td>
<td>31</td>
<td>37</td>
<td>43</td>
<td>49</td>
<td>55</td>
<td>61</td>
<td>67</td>
<td>74</td>
<td>80</td>
<td>86</td>
<td>93</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>35</td>
<td>42</td>
<td>49</td>
<td>56</td>
<td>63</td>
<td>70</td>
<td>77</td>
<td>85</td>
<td>92</td>
<td>99</td>
<td>107</td>
<td>114</td>
</tr>
<tr>
<td>35</td>
<td>39</td>
<td>47</td>
<td>55</td>
<td>63</td>
<td>71</td>
<td>78</td>
<td>86</td>
<td>95</td>
<td>103</td>
<td>111</td>
<td>119</td>
<td>127</td>
</tr>
<tr>
<td>40</td>
<td>43</td>
<td>52</td>
<td>60</td>
<td>69</td>
<td>77</td>
<td>86</td>
<td>95</td>
<td>104</td>
<td>113</td>
<td>121</td>
<td>130</td>
<td>139</td>
</tr>
<tr>
<td>45</td>
<td>47</td>
<td>56</td>
<td>65</td>
<td>75</td>
<td>84</td>
<td>93</td>
<td>103</td>
<td>112</td>
<td>122</td>
<td>131</td>
<td>141</td>
<td>150</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
<td>150</td>
<td>160</td>
</tr>
<tr>
<td>55</td>
<td>53</td>
<td>64</td>
<td>75</td>
<td>85</td>
<td>96</td>
<td>106</td>
<td>117</td>
<td>127</td>
<td>138</td>
<td>148</td>
<td>159</td>
<td>169</td>
</tr>
<tr>
<td>60</td>
<td>56</td>
<td>68</td>
<td>79</td>
<td>90</td>
<td>101</td>
<td>112</td>
<td>123</td>
<td>134</td>
<td>145</td>
<td>156</td>
<td>167</td>
<td>178</td>
</tr>
<tr>
<td>65</td>
<td>59</td>
<td>71</td>
<td>83</td>
<td>94</td>
<td>106</td>
<td>118</td>
<td>129</td>
<td>140</td>
<td>152</td>
<td>163</td>
<td>174</td>
<td>185</td>
</tr>
<tr>
<td>70</td>
<td>62</td>
<td>74</td>
<td>87</td>
<td>99</td>
<td>111</td>
<td>123</td>
<td>135</td>
<td>146</td>
<td>158</td>
<td>170</td>
<td>181</td>
<td>193</td>
</tr>
<tr>
<td>75</td>
<td>65</td>
<td>78</td>
<td>90</td>
<td>103</td>
<td>115</td>
<td>128</td>
<td>140</td>
<td>152</td>
<td>164</td>
<td>176</td>
<td>188</td>
<td>199</td>
</tr>
<tr>
<td>80</td>
<td>67</td>
<td>81</td>
<td>94</td>
<td>107</td>
<td>120</td>
<td>132</td>
<td>145</td>
<td>157</td>
<td>169</td>
<td>182</td>
<td>194</td>
<td>206</td>
</tr>
<tr>
<td>85</td>
<td>70</td>
<td>84</td>
<td>97</td>
<td>110</td>
<td>124</td>
<td>136</td>
<td>149</td>
<td>162</td>
<td>175</td>
<td>187</td>
<td>199</td>
<td>211</td>
</tr>
<tr>
<td>90</td>
<td>72</td>
<td>86</td>
<td>100</td>
<td>114</td>
<td>127</td>
<td>141</td>
<td>154</td>
<td>167</td>
<td>179</td>
<td>192</td>
<td>205</td>
<td>217</td>
</tr>
<tr>
<td>95</td>
<td>75</td>
<td>89</td>
<td>103</td>
<td>117</td>
<td>131</td>
<td>144</td>
<td>158</td>
<td>171</td>
<td>184</td>
<td>197</td>
<td>209</td>
<td>222</td>
</tr>
<tr>
<td>100</td>
<td>77</td>
<td>92</td>
<td>106</td>
<td>120</td>
<td>134</td>
<td>148</td>
<td>162</td>
<td>175</td>
<td>188</td>
<td>201</td>
<td>214</td>
<td>227</td>
</tr>
<tr>
<td>105</td>
<td>79</td>
<td>94</td>
<td>109</td>
<td>123</td>
<td>138</td>
<td>152</td>
<td>165</td>
<td>179</td>
<td>192</td>
<td>205</td>
<td>218</td>
<td>231</td>
</tr>
<tr>
<td>110</td>
<td>81</td>
<td>96</td>
<td>111</td>
<td>126</td>
<td>141</td>
<td>155</td>
<td>169</td>
<td>182</td>
<td>196</td>
<td>209</td>
<td>222</td>
<td>235</td>
</tr>
<tr>
<td>115</td>
<td>83</td>
<td>99</td>
<td>114</td>
<td>129</td>
<td>143</td>
<td>158</td>
<td>172</td>
<td>186</td>
<td>199</td>
<td>213</td>
<td>226</td>
<td>239</td>
</tr>
<tr>
<td>120</td>
<td>85</td>
<td>101</td>
<td>116</td>
<td>131</td>
<td>146</td>
<td>161</td>
<td>175</td>
<td>189</td>
<td>203</td>
<td>216</td>
<td>230</td>
<td>243</td>
</tr>
<tr>
<td>125</td>
<td>87</td>
<td>103</td>
<td>119</td>
<td>134</td>
<td>149</td>
<td>164</td>
<td>178</td>
<td>192</td>
<td>206</td>
<td>219</td>
<td>233</td>
<td>246</td>
</tr>
<tr>
<td>130</td>
<td>88</td>
<td>105</td>
<td>121</td>
<td>136</td>
<td>151</td>
<td>166</td>
<td>181</td>
<td>195</td>
<td>209</td>
<td>223</td>
<td>236</td>
<td>249</td>
</tr>
<tr>
<td>135</td>
<td>90</td>
<td>107</td>
<td>123</td>
<td>138</td>
<td>154</td>
<td>169</td>
<td>183</td>
<td>198</td>
<td>212</td>
<td>225</td>
<td>239</td>
<td>252</td>
</tr>
<tr>
<td>140</td>
<td>92</td>
<td>109</td>
<td>125</td>
<td>141</td>
<td>156</td>
<td>171</td>
<td>186</td>
<td>200</td>
<td>214</td>
<td>228</td>
<td>242</td>
<td>255</td>
</tr>
<tr>
<td>145</td>
<td>93</td>
<td>110</td>
<td>127</td>
<td>143</td>
<td>158</td>
<td>173</td>
<td>188</td>
<td>202</td>
<td>217</td>
<td>231</td>
<td>244</td>
<td>258</td>
</tr>
<tr>
<td>150</td>
<td>95</td>
<td>112</td>
<td>128</td>
<td>145</td>
<td>160</td>
<td>175</td>
<td>190</td>
<td>205</td>
<td>219</td>
<td>233</td>
<td>247</td>
<td>260</td>
</tr>
<tr>
<td>155</td>
<td>96</td>
<td>114</td>
<td>130</td>
<td>146</td>
<td>162</td>
<td>177</td>
<td>192</td>
<td>207</td>
<td>221</td>
<td>235</td>
<td>249</td>
<td>262</td>
</tr>
<tr>
<td>160</td>
<td>98</td>
<td>115</td>
<td>132</td>
<td>148</td>
<td>164</td>
<td>179</td>
<td>194</td>
<td>209</td>
<td>223</td>
<td>237</td>
<td>251</td>
<td>264</td>
</tr>
<tr>
<td>165</td>
<td>99</td>
<td>117</td>
<td>133</td>
<td>150</td>
<td>166</td>
<td>181</td>
<td>196</td>
<td>211</td>
<td>225</td>
<td>239</td>
<td>253</td>
<td>266</td>
</tr>
<tr>
<td>170</td>
<td>100</td>
<td>118</td>
<td>135</td>
<td>151</td>
<td>167</td>
<td>183</td>
<td>198</td>
<td>213</td>
<td>227</td>
<td>241</td>
<td>255</td>
<td>268</td>
</tr>
<tr>
<td>175</td>
<td>102</td>
<td>119</td>
<td>136</td>
<td>153</td>
<td>169</td>
<td>184</td>
<td>200</td>
<td>214</td>
<td>229</td>
<td>243</td>
<td>257</td>
<td>270</td>
</tr>
<tr>
<td>180</td>
<td>103</td>
<td>121</td>
<td>138</td>
<td>154</td>
<td>170</td>
<td>186</td>
<td>201</td>
<td>216</td>
<td>230</td>
<td>244</td>
<td>258</td>
<td>272</td>
</tr>
<tr>
<td>185</td>
<td>104</td>
<td>122</td>
<td>139</td>
<td>156</td>
<td>172</td>
<td>188</td>
<td>203</td>
<td>217</td>
<td>232</td>
<td>246</td>
<td>260</td>
<td>273</td>
</tr>
<tr>
<td>190</td>
<td>105</td>
<td>123</td>
<td>140</td>
<td>157</td>
<td>173</td>
<td>189</td>
<td>204</td>
<td>219</td>
<td>233</td>
<td>247</td>
<td>261</td>
<td>275</td>
</tr>
<tr>
<td>195</td>
<td>106</td>
<td>124</td>
<td>142</td>
<td>158</td>
<td>175</td>
<td>190</td>
<td>205</td>
<td>220</td>
<td>235</td>
<td>249</td>
<td>263</td>
<td>276</td>
</tr>
<tr>
<td>200</td>
<td>107</td>
<td>125</td>
<td>143</td>
<td>160</td>
<td>176</td>
<td>192</td>
<td>207</td>
<td>222</td>
<td>236</td>
<td>250</td>
<td>264</td>
<td>277</td>
</tr>
</tbody>
</table>
8. Ponderosa pine, Jeffrey pine, Coulter pine, and Bishop pine. Note: For California, when these species were in mixed-conifer stands, we used the mixed-conifer equation.

a. For site trees < 130 years old breast-height age, site index was calculated from Barrett (1978).

\[
SI = 100.43 - \left[ 1.198632 - 0.00283073A + \frac{8.44441}{A} \right] \left[ 128.8952205 \left[ 1 - EXP(-0.016959A) \right]^{1.23114} \right] \\
+ \left[ 1.198632 - 0.00283073A + \frac{8.44441}{A} \right] (H - 4.5) \right] + 4.5 ,
\]

where

\[
SI = \text{site index in feet for breast-height age 100 years, and} \\
A = \text{breast-height age.}
\]

b. For ponderosa pine over 130 years old, we used the equation below, which approximates the site curves in Meyer (1961).

\[
SI = [(5.328A^{-0.1} - 2.378)(H - 4.5)] + 4.5 ,
\]

where

\[
SI = \text{site index in feet at breast-height age 100 years, and} \\
A = \text{breast-height age.}
\]


Site index was approximated from the equation:

\[
SI = (72.68 - 8.8A^{0.45}) + 4.5 + \left[ 2.2614 - 1.26489 \left[ 1 - EXP(-0.08333A) \right]^{5} \right] (H - 4.5) ,
\]

where

\[
SI = \text{site index in feet at breast-height age 100 years, and} \\
A = \text{breast-height age.}
\]
10. Western red cedar (Kurucz 1987).

Although western red cedar was rarely chosen for a site tree, if it was chosen, we used the following equations adapted from Mitchell and Polsson (1987):

a. If age \( \leq 50 \) years, then:

\[
SI = \left( \frac{2500}{0.3048} \right) \left( \frac{[(H - 1.3) (0.05027 + 0.01411A + 0.000097667A^2)]}{[A^2 - (H - 1.3) (- 3.11785 - 0.02465A + 0.00174A^2)]} \right) + 4.5 ,
\]

where

\( SI \) = site index in feet for breast-height age 50 years, and
\( A \) = breast-height age.

b. If age > 50 years, then substitute \( H_a \) for variable \( H \) in the site index equation above.

\[
H_a = H + 0.02379545H - 0.000475909AH ,
\]

where

\( A \) = breast-height age.


Site index = 92.0


\[
SI = 78.07 + [(H - 4.5) \\
\times (3.51412 - 0.125483A + 0.0023559A^2 - 0.00002028A^3 + 0.00000064782A^4)] \\
- [(3.51412 - 0.125483A + 0.0023559A^2 - 0.00002028A^3 + 0.00000064782A^4) \\
\times (1.46897A + 0.0092466A^2 - 0.00023957A^3 + 0.000001122A^4)] ,
\]

where

\( SI \) = site index in feet for breast-height age 50 years, and
\( A \) = breast-height age.

---


\[ SI = \left( 0.60924 + \frac{19.538}{A} \right) H, \]

where

\[ SI = \text{site index in feet for breast-height age 50 years, and} \]

\[ A = \text{breast-height age.} \]

14. Douglas-fir, grand fir, and white fir in eastern Oregon and eastern Washington. Douglas-fir in silver fir zone in western Washington (Curtis and others 1974). Silver fir zone had a plant association where the first two characters were CF or CM and the elevation was over 1000 meters.

a. Breast-height age 100 years or less:

\[ SI = 4.5 + a + \left[ b \left( H - 4.5 \right) \right], \]

where

\[ a = 0.010006 \left( 100 - A \right)^2, \]
\[ b = 1.0 + \left[ 0.00549779 \left( 100 - A \right) \right] + (1.46842 \times 10^{-14}) \left( 100 - A \right)^7, \]

\[ SI = \text{site index in feet for breast-height age 100 years, and} \]

\[ A = \text{breast-height age.} \]

b. Breast-height age greater than 100 years:

\[ SI = 4.5 + a + \left[ b \left( H - 4.5 \right) \right], \]

where

\[ a = 7.66772 \left[ \text{EXP} - 0.95 \left( \frac{100}{A-100} \right)^2 \right], \]
\[ b = 1.0 - \left[ 0.730948 \left( \text{LOG}_{10} A - 2.0 \right)^{0.8} \right], \]

\[ SI = \text{site index in feet for breast-height age 100,} \]

\[ A = \text{breast-height age, and} \]

\[ \text{LOG}_{10} = \text{logarithm to the base 10.} \]
15. Western larch in western Washington and eastern Washington; and western white pine in eastern Washington (Brickell 1970).

These equations replaced Cochran (1985) equations for the same areas and species beginning in 1990.

\[ SI = 0.37956H \exp \left( \frac{48.4372}{A + 8} \right), \]

where

\( SI \) = site index in feet for breast-height age 50 years, and

\( A \) = breast-height age.

16. Mixed conifer in California for all stands coded as mixed conifer. Note that as originally developed and published, this equation used a base age of 50 years, total age, and total height. The equations below were modified to accept breast-height age, the variable that our inventories normally measured.

Site species that could be used include: Douglas-fir, bigcone Douglas-fir, white fir, ponderosa pine, Jeffrey pine, Shasta red fir, red fir, and Coulter pine.

Site index equation derived from Dunning and Reineke (1933).

\[ SI = H \left( 0.25489 + \frac{29.377}{A} \right), \]

where

\( SI \) = site index in feet for breast-height age 100 years, and

\( A \) = breast-height age.

17. Red fir, Shasta red fir in California (Schumacher 1928).

Note that as originally developed and published, this equation used a base age of 50 years, total age, and total height. The equations below were modified to accept breast-height age, the variable that our inventories normally measured.

Note: For California, when Shasta red fir and red fir were in mixed-conifer stands, the mixed-conifer site index equation was used.

Site index approximated by equation derived from Schumacher (1928):

\[ SI = H \left( 0.1464 + 43.3273A^{-1.1} \right), \]

where

\( SI \) = site index in feet for breast-height age 50 years, and

\( A \) = breast-height age.
Mean Annual Increment

Foresters use MAI to describe the wood-growing capacity of a site, expressed by PNW-FIA as the average increase in cubic-foot volume per acre per year. As we used the term, it was defined as the increment (increase in volume) of a timber stand averaged over the period between age zero and the age at which MAI culminates, i.e., reaches its maximum value.

Mean annual increment equations, also called yield equations, were derived by PNW-FIA from yield data found in published normal yield tables. These normal yield studies were done for a particular species by taking tree measurements (diameter, height, and age, to determine individual tree volume) from many representative sample areas, and then computing basal area per acre, trees per acre, mean diameter, height and diameter of average tree, and volume. The result was a set of tables of growth and yield data representing a fully stocked stand.

The PNW-FIA bases the MAI equations on site index. This calculated MAI value is then modified by discount factors applicable to the plot or region.

MAI Discount Factors

Discount factors, also called weighted or stockability discount factors, were used by PNW-FIA when normal yield tables could overestimate productivity. This could happen if (1) the site would never be able to support normal stocking because of environmental factors such as poor soil types, yet the site index could imply normal productivity; (2) the resources of the site could support more trees than were present; or (3) when parts of the plot were nonstockable but still classed as forest land (rock outcroppings, small streams, etc.) and so appeared to be understocked. The PNW-FIA had two discount factors to adjust for this: plant stockability factor and nonstockable factor.

A discount factor of less than 1.0 indicated that the site was not capable of carrying normal levels of stocking as defined by the appropriate normal yield table.

Plant stockability factor was developed by PNW-FIA for use in regions where the potential stocking could vary widely owing to natural causes (MacLean and Bolsinger 1973). The field crew recorded the presence of certain plant species, called stockability indicator plants, in western Oregon (Douglas, Jackson, and Josephine Counties only), and California (except the north coast and central coast areas). In eastern Oregon and eastern Washington, the Pacific Northwest Region Forest Service plant association/ecoclass code was collected based on local plant association manuals classifying the plants found on the site (Hall 1998). All other regions had the plant stockability factor set to 1.0.

These stockability indicator plants indicated soil moisture problems and toxic (serpentinite) soils. The plant data were used with other environmental variables, such as elevation, to compute the plant stockability factor for these plots.

Nonstockable factor was the percentage of nonstockable land estimated by the field crew for each subplot on the plot. Small streams, ponds, compacted landings, bedrock, and rock outcroppings are examples of areas that can prevent full stocking. (Also called “nonforest inclusions” and “nonstockable nonforest percent”). This was subtracted from the total subplot area to obtain the percentage of the subplot that is capable of full stocking.
Calculating Adjusted MAI

After the site index was calculated for the plot, the analyst selected the appropriate MAI equation based on the site species and geographic area (table 3) and calculated an unadjusted (unadjusted for discounts) MAI for each subplot in timberland. Then the nonstockable percentage was calculated and the plant stockability factor applied, if required. (This step also was called multiplying by the weighted plot discount factor). Finally, an adjusted MAI for the entire plot was made by averaging adjusted MAIs for all the subplots.

Since 1991, PNW-FIA mapped and collected plot data based on the “condition class” encountered on the plots. If there were two or more timberland condition classes, and only one had nonstockable area, then an MAI was calculated and reported for each condition class on the plot. If the nonstockable area occurred across the condition classes, the MAI was averaged over subplots as usual, and only one MAI was calculated and reported for the plot.

Using the MAI

In forestry, the MAI is used in economic analyses and determinations of forest policy because it can be associated with value and rate of return on investment. At PNW-FIA, the MAI was primarily used to develop the site classes: six classes of volume growth per acre at culmination in fully stocked natural stands. The site classes were in a standard table in resource bulletins, “Area of timberland by owner and site class” (for example, Bolsinger and others 1997).

The PNW-FIA also used the MAI to divide plots between “timberland” and “other forest low productivity” (formerly called “noncommercial forest land”), based on whether the site could produce 20 cubic feet • acre⁻¹ • year⁻¹.

The Adjusted MAI

The adjusted MAI (adjusted for the two discount factors) was the MAI reported for the plot in the FIA national database and the published tables.

MAI Equations

The following equations express the yield in cubic feet per acre per year.

\[ MAI = \text{mean annual increment}, \]
\[ SI = \text{site index for that species and area}, \]
\[ EXP = \text{natural exponent, and} \]
\[ Ln = \text{natural log}. \]


\[
\begin{align*}
MAI &= -60 + 1.71SI \quad \text{when site index} < 75 \\
MAI &= -81.3 + 2.02SI \quad \text{when site index} \geq 75, \leq 130 \\
MAI &= 22.9 + 1.21SI \quad \text{when site index} > 130 
\end{align*}
\]


\[ MAI = 1.8SI - 57.12 . \]
Table 3—Mean annual increment (MAI) equation assignments

<table>
<thead>
<tr>
<th>MAI equation number</th>
<th>Species</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Douglas-fir and grand fir</td>
<td>WOR (after 1984) except Jackson and Josephine Counties, WWA except in silver fir zone, CA except in mixed-conifer stands</td>
</tr>
<tr>
<td>2</td>
<td>Douglas-fir</td>
<td>Jackson and Josephine Counties in WOR</td>
</tr>
<tr>
<td>3</td>
<td>Grand fir and white fir</td>
<td>Jackson and Josephine Counties in WOR</td>
</tr>
<tr>
<td>4</td>
<td>Western hemlock and Sitka spruce</td>
<td>WOR, EOR, WWA, EWA, CA</td>
</tr>
<tr>
<td>5</td>
<td>Redwood</td>
<td>WOR, CA</td>
</tr>
<tr>
<td>6</td>
<td>Noble fir, Shasta red fir in OR, Pacific silver fir, subalpine fir, mountain hemlock</td>
<td>WOR, EOR, WWA, EWA, CA</td>
</tr>
<tr>
<td>7</td>
<td>Ponderosa pine, Jeffrey pine, Coulter pine, Bishop pine</td>
<td>WOR, EOR, WWA, EWA, CA</td>
</tr>
<tr>
<td>8</td>
<td>Douglas-fir</td>
<td>EOR, EWA</td>
</tr>
<tr>
<td>9</td>
<td>White fir and grand fir</td>
<td>EOR, EWA</td>
</tr>
<tr>
<td>10</td>
<td>Lodgepole pine, western white pine except in EWA</td>
<td>EOR, WWA, CA</td>
</tr>
<tr>
<td>11</td>
<td>Lodgepole pine</td>
<td>EWA</td>
</tr>
<tr>
<td>12</td>
<td>Western larch</td>
<td>EOR</td>
</tr>
<tr>
<td>13</td>
<td>Western larch</td>
<td>WWA, EWA</td>
</tr>
<tr>
<td>14</td>
<td>Engelmann spruce</td>
<td>EOR, WWA, EWA</td>
</tr>
<tr>
<td>15</td>
<td>Douglas-fir in silver fir zone</td>
<td>WWA</td>
</tr>
<tr>
<td>16</td>
<td>Western red cedar</td>
<td>WWA, WOR, CA</td>
</tr>
<tr>
<td>17</td>
<td>Western white pine</td>
<td>EWA</td>
</tr>
<tr>
<td>18</td>
<td>Mixed conifer</td>
<td>CA</td>
</tr>
<tr>
<td>19</td>
<td>Red fir, Shasta red fir in CA, white fir in CA</td>
<td>CA</td>
</tr>
<tr>
<td>20</td>
<td>All hardwoods</td>
<td>WOR, EOR, WWA, EWA, CA</td>
</tr>
</tbody>
</table>

WOR = western Oregon.
WWA = western Washington.
EOR = eastern Oregon.
EWA = eastern Washington.

\[ MAI = 1.9407SI - 34. \]


\[ MAI = 2.628SI - 49.8. \]


\[ MAI = EXP (0.2995 \sqrt{SI} + 2.404). \]


\[ MAI = 1.6SI - 50. \]


\[ MAI = EXP (0.702695SI^{0.42} - 0.51367). \]


\[ MAI = 0.00473SI^{2.04}. \]


\[ MAI = EXP (8.24227 - 23.53735SI^{-0.4}). \]


\[ MAI = 0.8594SI - 22.32. \]


\[ MAI = 0.0122SI^{2} - 0.2026SI + 7.4. \]


\[ MAI = EXP \left[ 0.05 - \frac{72.1299}{63.8 - 0.066SI} + 1.4 \ln (SI - 20) \right]. \]


\[ MAI = -126.05 + (2.7974081SI) + \frac{1919.3157}{SI}. \]
14. Engelmann spruce in eastern Oregon, western Washington, and eastern Washington.\textsuperscript{4}

\[ MAI = (1.92SI) - 18.4. \]


\[ MAI = 1.166SI - 50. \]


\[ MAI = 2.628SI - 49.8. \]

17. Western white pine in eastern Washington (Brickell 1970).

\[ MAI = 14.849891 + 1.7311563SI. \]

18. Mixed conifer in California (Dunning and Reineke 1933).

\[ MAI = EXP(0.578265SI^{0.4} + 1.8108). \]

19. Red fir, Shasta red fir in California, white fir in California (Schumacher 1928).

\[ MAI = 48.278 + 0.23638SI^{1.6}. \]

20. All hardwoods (Worthington and others 1960).

\[ MAI = (1.7102SI) - 53.1279. \]

Codominant—The tree’s crown is part of the general level of the canopy; it receives full light from above but little light from the sides. Crown is usually medium sized and somewhat crowded by other trees.

Condition class—a mapped area on a plot with a distinct land class (for example, timberland, oak woodland, nonforest) or a distinctive vegetative condition (for example, forest type, stand size). The condition class identified at a plot center is the only condition class that is remeasured and used for the analysis of periodic change.

Discount factor—An element of the MAI equation applied if one or both of the two PNW-FIA discount factors (plant stockability factor and nonstockable factor) are present on the field plot. It is also called weighted or stockability discount factor.

Dominant—The tree’s crown extends above the general level of the canopy; it receives full light from above and some direct light from the sides (includes open-grown trees).

Forest land—A plot is established on the ground if the crew determines that the site meets the definition of “forest land.” Forest land is land that is within the sampled area, is accessible, can be safely visited, and meets at least one of the following two criteria: (1) is (or has been) at least 10 percent stocked with trees of any size as well as not subject to nonforest use that would prevent regeneration, such as mowing, grazing, or recreation; or (2) has western woodland types (tree species not treated as timber species by PNW-FIA) and has (or previously had) at least 5 percent crown cover by trees of any size, and is not subject to nonforest use. In the PNW-FIA National Core Field Guide (used in the annual inventory starting in 2000), “forest land” is one of six kinds of condition status, which delineate the condition classes, and is the only one on which plots are measured for the inventory.

Mainstand—The stand that is currently available for management for timber production. All trees that are not understory seedlings or saplings, or residual overstory.

Mixed conifer—The PNW-FIA classifies some areas of California forests as mixed conifer if there is no main softwood tree species as the forest type. A mixed-conifer site is capable of greater than 70 percent conifer stocking, occurs in certain counties, and is further defined by the predominance of certain tree species. In general, these plots have some mix of ponderosa pine, Jeffrey pine, sugar pine, Douglas-fir, red fir, Shasta red fir, incense cedar, and white fir.

Mixed-conifer types grow on the east-facing slopes of the Coast Range, on the west-facing and higher elevation east-facing slopes of the Cascade Range and Sierra Nevada, and can extend into southern California.

Other forest-low productivity—Forest land capable of growing crops of trees to industrial roundwood quality but not able to grow wood at the rate of 20 cubic feet • acre\(^{-1}\) • year\(^{-1}\). Included are areas of low stocking potential or very low site index.
Silver fir zone in western Washington—The area in western Washington where the first two digits of the Pacific Northwest Region Forest Service plant association/eco-class code are CF (silver fir, noble fir) or CM (mountain hemlock) and the elevation is over 1000 meters (3,000 feet).

Suppressed—A suppressed tree is completely overtopped by other trees and not free to grow.

Timberland—Forest land that is potentially capable of producing at least 20 cubic feet•acre⁻¹•year⁻¹ at culmination in fully stocked, natural stands of continuous crops of trees to industrial roundwood size and quality. Industrial roundwood requires species that grow to size and quality adequate to produce lumber and other manufactured products (excluding fence posts and fuel wood, which are not considered manufactured). Timberland is characterized as having no severe limitations on artificial or natural restocking with species capable of producing industrial roundwood. “Timberland” is one of three categories of ground land class; the other two are “other forest” and “non-forest.”

Western woodland types—Tree species designated in the PNW-FIA National Core Field Guide (used in the annual inventory since 2000) as those species for which diameter is measured at root crown: juniper, pinyon pine, mountain mahogany, etc.

Yield—The volume of wood that may be contained in a particular type of forest stand.

Metric Equivalents
1 foot = 0.3048 meter
1 acre = 0.405 hectare
1 cubic foot per acre = 0.07 cubic meter per hectare

Literature Cited


## Appendix 1

### Names of Trees

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bigcone Douglas-fir</td>
<td><em>Pseudotsuga macrocarpa</em> (Vasey) Mayr</td>
</tr>
<tr>
<td>Bishop pine</td>
<td><em>Pinus muricata</em> D. Don</td>
</tr>
<tr>
<td>Black cottonwood</td>
<td><em>Populus balsamifera ssp. trichocarpa</em> (Torr. &amp; Gray ex Hook.) Brayshaw</td>
</tr>
<tr>
<td>Coulter pine</td>
<td><em>Pinus coulteri</em> D. Don</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td><em>Pseudotsuga menziesii</em> (Mirbel) Franco</td>
</tr>
<tr>
<td>Englemann spruce</td>
<td><em>Picea englemannii</em> Parry ex Engelm.</td>
</tr>
<tr>
<td>Fremont poplar</td>
<td><em>Populus fremontii</em> S. Wats.</td>
</tr>
<tr>
<td>Grand fir</td>
<td><em>Abies grandis</em> (Dougl. ex D. Don) Lindl.</td>
</tr>
<tr>
<td>Incense cedar</td>
<td><em>Calocedrus decurrens</em> (Torr.) Florin</td>
</tr>
<tr>
<td>Jeffrey pine</td>
<td><em>Pinus jeffreyi</em> Grev. &amp; Balf.</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td><em>Pinus contorta</em> Dougl. ex Loud.</td>
</tr>
<tr>
<td>Mountain hemlock</td>
<td><em>Tsuga mertensiana</em> (Bong.) Carr.</td>
</tr>
<tr>
<td>Noble fir</td>
<td><em>Abies procera</em> Rehd.</td>
</tr>
<tr>
<td>Pacific silver fir</td>
<td><em>Abies amabilis</em> (Dougl. ex Loud.) Dougl. ex Forbes.</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td><em>Pinus ponderosa</em> P. &amp; C. Lawson</td>
</tr>
<tr>
<td>Red alder</td>
<td><em>Alnus rubra</em> Bong.</td>
</tr>
<tr>
<td>Red fir</td>
<td><em>Abies magnifica</em> A. Murr.</td>
</tr>
<tr>
<td>Redwood</td>
<td><em>Sequoia sempervirens</em> (Lamb. ex D. Don) Endl.</td>
</tr>
<tr>
<td>Shasta red fir</td>
<td><em>Abies shastensis</em> (Lemmon) Lemmon</td>
</tr>
<tr>
<td>Sitka spruce</td>
<td><em>Picea sitchensis</em> (Bong.) Carr.</td>
</tr>
<tr>
<td>Subalpine fir</td>
<td><em>Abies lasiocarpa</em> (Hook.) Nutt.</td>
</tr>
<tr>
<td>Sugar pine</td>
<td><em>Pinus lambertiana</em> Dougl.</td>
</tr>
<tr>
<td>Western hemlock</td>
<td><em>Tsuga heterophylla</em> (Raf.) Sarg.</td>
</tr>
<tr>
<td>Western larch</td>
<td><em>Larix occidentalis</em> Nutt.</td>
</tr>
<tr>
<td>Western red cedar</td>
<td><em>Thuja plicata</em> Donn ex D. Don</td>
</tr>
<tr>
<td>Western white pine</td>
<td><em>Pinus monticola</em> Dougl. ex D. Don</td>
</tr>
<tr>
<td>White fir</td>
<td><em>Abies concolor</em> (Gord. &amp; Glend.) Lindl. ex Hildebr.</td>
</tr>
</tbody>
</table>

Appendix 2

Base age of original site index equation (whether it was based on 50- or 100-year age, and whether the equation was originally written with the individual tree’s total or breast-height age [BHA]).

Table 4—Site index equation base age

<table>
<thead>
<tr>
<th>Site index equation number</th>
<th>Source</th>
<th>Original equation age</th>
<th>Basis</th>
<th>PNW-FIA equation age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>King 1966</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>McArdle and others 1961&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100</td>
<td>Total</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>Cochran 1979b</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Cochran 1979c</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>Herman and others 1978</td>
<td>100</td>
<td>BHA</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Wiley 1978</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Barnes 1962&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Brickell 1966</td>
<td>50</td>
<td>Total</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Krumland and Wensel 1977</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>Barrett 1978</td>
<td>100</td>
<td>BHA</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Meyer 1961</td>
<td>100</td>
<td>BHA</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>Dahms 1975</td>
<td>100</td>
<td>BHA</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>Kurucz 1987</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>11</td>
<td>Bolsinger 1974&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50</td>
<td>Total</td>
<td>50</td>
</tr>
<tr>
<td>12</td>
<td>Cochran 1985</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>13</td>
<td>Worthington and others 1960</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>Curtis and others 1974</td>
<td>100</td>
<td>BHA</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>Brickell 1970</td>
<td>50</td>
<td>Total</td>
<td>50</td>
</tr>
<tr>
<td>16</td>
<td>Dunning and Reineke 1933&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50</td>
<td>BHA</td>
<td>100</td>
</tr>
<tr>
<td>17</td>
<td>Schumacher 1928</td>
<td>50</td>
<td>BHA</td>
<td>50</td>
</tr>
</tbody>
</table>

<sup>a</sup> Some site index equations, for example no. 1: McArdle’s Douglas-fir (McArdle and others 1961), were derived by PNW-FIA from the site index curves in the cited publication because there was no equation published. In these cases, the derived equation was sometimes written by using a different base age to better fit the available site trees. The citation reflects the publication that had the original curves.

<sup>b</sup> See footnote 3
The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater Service to a growing Nation.

The United States Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, gender, religion, age, disability, political beliefs, sexual orientation, or marital or family status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 14th and Independence Avenue SW, Washington, DC 20250-9410 or call (202) 720-5964 (voice and TDD). USDA is an equal opportunity provider and employer.